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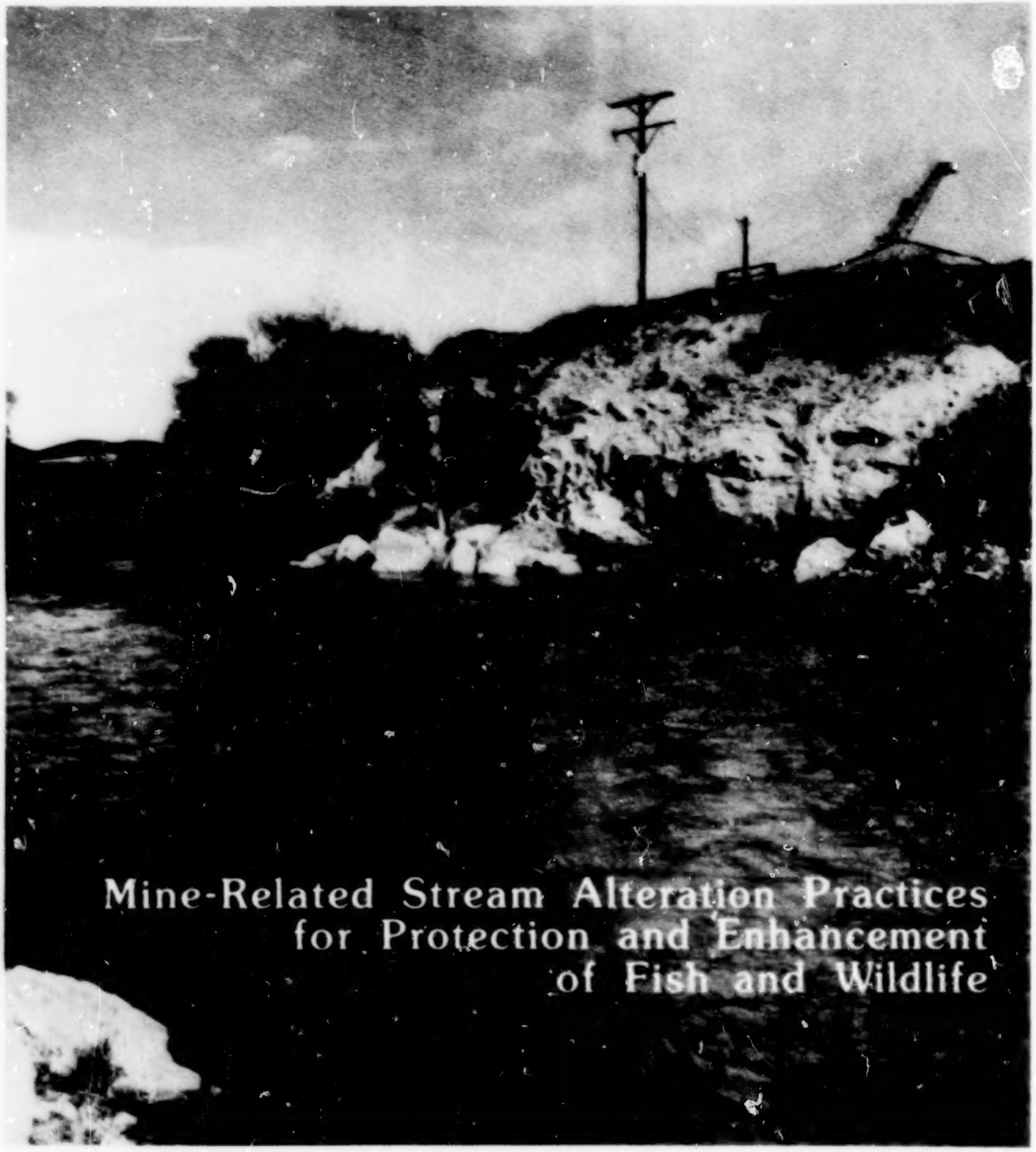

Mine-Related Stream Alteration Practices for Protection and Enhancement of Fish and Wildlife

Fish and Wildlife Service
Office of Surface Mining Reclamation and Enforcement

U.S. Department of the Interior

March 3 1849

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

EASTERN ENERGY AND LAND USE TEAM
Route 3, Box 44
Kearneysville, West Virginia 25430

May 10, 1983

Dear Colleague:

The Eastern Energy and Land Use Team is pleased to provide you with a copy of "Mine-Related Stream Alteration Practices for Protection and Enhancement of Fish and Wildlife," FWS/OBS-82/57. The document contains valuable reference information for use in developing mine site plans that involve relocating and/or protecting small streams on and adjacent to mining operations. The coverage is national in scope. Some techniques are broadly applicable while others are more regional oriented.

The "practices" should be considered as recommendations and possible alternatives based on experienced use. It is recognized that some practices may be omitted and that new practices, not contained in this document, may prove valuable for small stream protection measures.

Sincerely,

Edgar A. Pash

Edgar A. Pash
Team Leader

A

FWS/OBS-82/57
October 1982

MINE-RELATED STREAM ALTERATION PRACTICES FOR PROTECTION AND ENHANCEMENT OF FISH AND WILDLIFE

by

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PREFACE

Small streams located on or adjacent to coal surface mines are subject to possible alterations during and after cessation of mining operations. In many cases these streams must be relocated or provided special attention to avoid loss of physical, chemical and/or biological integrity. This document provides surface mining planners, managers and biologists with up-to-date information on mining related stream alterations and alternative practical methods proven beneficial for protection and enhancement of fish and wildlife. Some methods have wide national utility while others are more regionally oriented. First hand consultation with state surface mining reclamation agencies will help ensure selection of the best practices for any particular mine site plan.

EXECUTIVE SUMMARY

The extraction of coal can be conducted without permanent long term damage to our nation's fish and wildlife resources if proper engineering and environmental considerations are included early in the mining process. Due to their complex nature, streams are particularly sensitive to the potential effects resulting from coal mining and associated operations, and these effects are of primary concern to state and federal agencies responsible for reviewing and granting permits to mine coal. Thus, there is a high level of awareness on the part of both the mine operators and regulatory agencies regarding the possible consequences of affecting or altering streams, while at the same time, economic, technological and/or topographic constraints may dictate that some disturbance of streams is necessary during the development or operation of a coal mine.

The main purpose of this document is not to resolve this conflict between preservation of natural conditions and development of our energy resources. Instead, the intent is to present practices and techniques that have been or could be employed by operators to protect and enhance biological communities of streams from coal mining activities that have the potential to adversely affect these resources. This document will encourage dialogue between operators and agency personnel by providing concepts and ideas to serve as a common basis for discussion.

The approach taken in developing this report was to first identify stream alterations resulting from coal mines including their causes, effects, and measures employed to eliminate or reduce their consequences. From this information, a list of current practices was compiled and their effectiveness and practicality evaluated. When possible, practices were examined under field conditions at mine sites where they have been utilized.

General discussions of important hydrologic and biologic stream characteristics are provided to serve as a basis for introducing practices and procedures to minimize impacts of stream alterations. Recognition of hydrologic/hydraulic conditions and processes are critical to the design and implementation of projects that involve stream alterations. In particular, streamflow extremes (minimum and peak discharge events), stream forces, stream type, the relationships among physical stream parameters, erosion of streambeds and banks, and the role of floodplains are addressed as important considerations in understanding the myriad of physical interactions occurring in streams. The biological component of streams is no less complex and requires an appreciation for the types of organisms typically inhabiting streams, including organismic life requisites and the relationships between physical and biological systems. The discussions also include some of the more common methods for classifying streams.

Stream alterations, defined as a man-induced change to a stream, can occur as physical modifications (changes in direction or dimensions), as hydraulic/hydrologic alterations (e.g., flow reductions, flooding, aggragation, degradation) or as water quality alterations (e.g., changes to concentrations of suspended solids, pH and turbidity fluctuations, elevated dissolved solids, etc.). Stream alterations commonly associated with the major phases of coal mining such as exploration, development, production and reclamation are presented and the potential effects of these alterations, both physical and biological, are listed.

To counteract these potential effects, this document presents the practices involved and the proper implementation of activities that affect streams during the life of a coal mine, as well as measures that can be taken to protect and improve fish and wildlife resources from stream alteration projects. Important topics that are addressed include stream diversions, alternatives to channelization, stream impoundments, stream crossings and practices to reduce or eliminate changes to water quality conditions in streams receiving drainage from the mine site. Stream improvement techniques discussed in the document encompass structures that can be used to provide habitat or improve flow or water depth conditions; devices to allow passage of fish around stream obstructions; and procedures to rehabilitate stream substrate conditions.

To illustrate utilization of technologies presented in the document, simulated mining situations that require stream alterations are provided in the appendices along with proposed measures to protect or enhance aquatic resources. Also included in the appendices are lists of state and federal agencies to contact for information and guidance in the event stream alterations are necessary during the course of mining activities.

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Federal

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CHAPTER 1 - INTRODUCTION

PURPOSE

This document was developed to provide techniques or practices that are being used or can be used to protect and enhance aquatic resources from stream alterations that may result from surface mining operations. Stream alterations, as considered in this reference document, refers to any man-made change, either beneficial or adverse, that has occurred to a stream.

Numerous practices have been developed to protect, restore and enhance aquatic life in streams that have been disturbed or altered by projects such as highways, flood control structures, haul roads and other projects associated with the construction, operation, or reclamation of major facilities. However, only a few of these practices have been applied directly to streams affected by with mining operations and those that have been used are primarily confined to the protection of water quality such as erosion and sedimentation control, or acid mine drainage treatment.

This document is intended to serve as a general reference for mine operators, reclamation specialists, and various state and federal fish and game agencies who have a role in providing recommendations regarding methods to protect and enhance streams and aquatic resources during mining activities. Others who may have a need for planning construction projects that result in disturbances in and around streams and are looking for practices that will protect aquatic life may also consider using ideas included in this document.

The intent of this reference document is not to burden the mine operator with additional regulatory requirements, but rather to provide ideas and options that are available to protect and enhance aquatic resources. This document should serve as a basis for discussions with review and regu- agencies which may be unfamiliar with practical approaches to stream alterations as they relate to mining practices.

The focus of this document is to present technologies or practices that are directly applicable to mine sites throughout the coal-producing regions of the United States. For the most part, the practices can be implemented at a reasonable cost to the mine operator if proper planning is initiated early in the conceptual stages of the mine. It should be stressed that the practices in this document should only be implemented after consultation with the local fish or game biologists. Although the practices presented herein are applicable to most mine sites, any given practice could result in adverse impacts to the aquatic life of a stream if it is not properly planned or designed by a qualified biologist and engineer.

STUDY METHODS

The approach used to meet the project objectives consisted of three major phases. The first phase was initiated by identifying the major stream alterations that result from surface mining; their biological effects; and measures that were being used or could be used to protect and enhance aquatic resources before, during, and after mining. The information developed during this phase of the study was accomplished by conducting an in-depth literature search and by contacting mine operators and a number of recognized authorities.

The second phase of the study included compiling a list of the current technologies or practices available; developing criteria to evaluate the practices from an ecological, engineering, economic, geographic and regulatory standpoint; and then producing a final list of protection and enhancement practices that could be applied to stream alterations resulting from surface mining activities. To complete this portion of the study, a number of sites were visited to document the practicality and effectiveness of the practices. These sites included surface and underground mines, highway projects, as well as other sites where protection and enhancement practices were being carried out or had been conducted in the past. Site visits were made in the Eastern, Interior, and Mountain Coal Provinces. In addition, numerous contacts were made with state agencies in coal producing states and with coal operators to obtain input for this document.

The third and final phase of the study resulted in the preparation of this report. A draft copy of the document was submitted to various mine operators, the U.S. Fish and Wildlife Service, several federal and state review agencies, and recognized fisheries authorities for review and comment. The draft report was then revised to incorporate comments and a final copy was prepared.

USE OF THE DOCUMENT

The information in this document is organized into five chapters. This chapter includes an overview of the contents and rationale that went into its development. Chapter 2 discusses the interrelationship of the physical and biological characteristics of a stream system, and serves as a preface to the practices and techniques currently available to address stream alterations, including the interrelationship of geomorphology, hydraulic/hydrologic engineering and aquatic ecology. Chapter 3 is devoted to identifying and defining stream alterations attributable to surface coal mining. The chapter focuses on specific situations encountered during the main phases of mining and potential consequences these actions may have from a physical and ecological standpoint. Chapter 4 outlines a number of practices and techniques that have been implemented or that are applicable to surface mined lands to prevent or minimize potential adverse effects of stream alterations on fish and wildlife. This chapter provides a step-by-step process of the design and construction of the relocation of s as well as alternatives available for increasing channel capacities without severely disturbing an existing stream. Chapter 5 discusses the methods that are available to enhance fish and wildlife on streams that are affected on or near the mine operation. These enhancement practices incorporate various structures into the channel design of a stream relocation or modification.

In addition, two appendices have been included. Appendix A provides three hypothetical case studies corresponding to each of the three coal producing regions of the United States. Each of the hypothetical case studies presents approaches for minimizing the effects of a stream alteration utilizing practices presented in the main text of the document. Illustrations are used to develop the concepts of each case study. Appendix B contains a list of state and federal agencies that can be contacted for additional information.

GENERAL STUDY ASSUMPTIONS

In preparing this document, certain assumptions were made so the information presented in this study would be of manageable size and to reduce the amount of information that is sufficiently described in other publications. The focus of this document was to provide the type and detail of information necessary to assist mine operators, reclamation specialists, planners, and fish and wildlife agencies develop biologically sound plans which protect and enhance sensitive aquatic life and habitat.

The material is generally presented without consideration of the numerous state and federal regulations pertaining to the mining and reclamation of surface coal mines. Instead, the emphasis was placed on presenting practices or technologies that are currently being carried out or could be carried out on a mine site that are acceptable from an engineering standpoint, but will also provide benefits to aquatic resources. In addition, consideration was not given to various state (e.g., Stream Encroachment Permit) or federal (e.g., Army Corps of Engineers 404 Permit) permits that may be required before altering of the stream is allowed. The information concerning the requirements for such permit applications is available from the appropriate regulatory agency.

Finally, the material presented herein cannot be routinely applied to every mine site. Instead, the objective was to provide ideas and options that can be adapted to actual site conditions.

RESEARCH/INFORMATION NEEDS

As this project progressed, it became obvious that current scientific literature regarding practices to protect and/or enhance aquatic resources in streams experiencing mining-related alterations is not available for certain informational areas. Documentation is needed for:

1. Determining the success (in terms of increased productivity, species diversity or other numerical indications) of installing devices or structures to improve habitat conditions in altered streams on mined lands.
2. Evaluating the benefits versus costs of implementing stream enhancement or protection practices in the coal mining environment.

In retrospect, it is not suprising that these informational needs exist because mining requirements directed toward preservation or re-establishment of original stream characteristics and habitat have only recently become part of the nationwide regulatory process. Thus, there is an insufficient "track record" for stream enhancement techniques on mined lands to discuss any resultant quantitative benefits derived from providing specific measures for fish and wildlife resources.

Ascertaining benefit/cost ratios or other economic parameters which are used to discuss the advantages or disadvantages of utilizing a particular stream alteration practice was not attempted during this study. This was due in large part to the limited information available on documented costs but also because stream alteration projects involve tasks that are not readily discernable from other mining activities. For example, the costs involved with the earthmoving required to construct a new channel for a relocated stream are generally not kept apart from overburden and reclamation expenses by most mine operators. Their major concern is that production of coal is not interrupted or delayed and the extra costs involved with a stream project are secondary in importance unless the project affects normal operational activities. Also, coal companies are understandably reluctant to release mining and reclamation costs to the general public. Another problem arises when assigning benefits to enhancement of fish and wildlife habitat because this type of analysis lacks a standardized approach to valuing wildlife species that are not commercially exploitable or that directly relate to recreational usage.

As a result, this document does not stress the economic justification for selecting practices to mitigate stream alteration effects. Cost estimation will be dependent on available resources, equipment and manpower available to the operator and such costs must be balanced by the commercial, recreational and aesthetic benefits gained by protecting and preserving stream systems. Thus, implementation of particular techniques should, until scientific and economic merits are documented, be part of a negotiation process between the operator and the regulatory agency and be based on site-specific conditions.

CHAPTER 2 - STREAM CHARACTERISTICS

PHYSICAL CHARACTERISTICS

The Hydrologic Cycle

The quantity and quality of water contained in a stream is the result of a complex interaction of chemical and physical factors that include climate, topography, vegetation, soils and geologic conditions. Figure 2-1 represents a simplified version of the hydrologic cycle and its major components--precipitation, surface runoff, evaporation, interception, depression storage and infiltration. Precipitation, in the form of rain and snow, distributes water over the land surface. The portion of the precipitation that reaches the stream through overland flow is termed surface runoff. Surface runoff is of concern in stream alteration projects because engineering design of channels and stream crossings are based on storm or flood stream flows. In addition surface runoff contributes to soil erosion and sediment transport.

Evaporation from land and water surfaces is a direct mechanism by which water is returned to the atmosphere as vapor and serves as a recycling step within the hydrologic cycle. Factors affecting the rate of evaporation include solar radiation, air temperature, vapor pressure, wind and, to some extent, atmospheric pressure (Linsley, et al. 1982).

Interception occurs when rain (or snow) is caught in the vegetation before it reaches the land surface (soil). In this case water evaporates at a rate determined primarily by the amount of solar radiation to which it is exposed.

Some of the precipitation falls directly onto low lying areas or, as a result of overland flow, enters these areas before reaching a stream. Water trapped under these conditions is said to be in depression storage. The puddles observed after a rainfall are an example of depression storage.

Precipitation which enters the soil is called infiltration. The fate of this water is varied. A small portion percolates through the soil, into deep, porous geologic strata and is essentially lost to the system. Some is retained in the soil layer in voids or held between soil particles by hydrostatic forces. Most of the infiltrated water is either absorbed by plant root systems or enters the groundwater system. The uptake of water by plants is an extremely important phase of the hydrologic cycle because most of this water escapes from the leaves as vapor through the process of transpiration. Transpiration has been defined as "the principal mechanism by which the precipitation falling on land areas is returned to the atmosphere" (Linsley, et al. 1982). When studying an area to determine the hydrologic balance, the separation of evaporation and transpiration quantities is not practical. Therefore, these components are generally combined and the term evapotranspiration is used to describe water losses attributable to these phenomena.

Precipitation that becomes part of the ground or subsurface water provides the base (dry weather) flow for permanent streams and contributes to the flows of seasonal streams through springs or shallow seeps where the groundwater level and the land surface intersect. Groundwater release to streams is generally slow and steady, thereby providing a constant source of water to those streams fed by subsurface supplies.

Hydrologic Events

Alteration of one or more of the components of the hydrologic cycle will affect flow in streams. In particular, rainfall variations will greatly modify stream flows since only a portion of the total precipitation for a year actually enters streams. For this reason, estimates of stream flow must be based on statistical analysis of long-term discharge records which

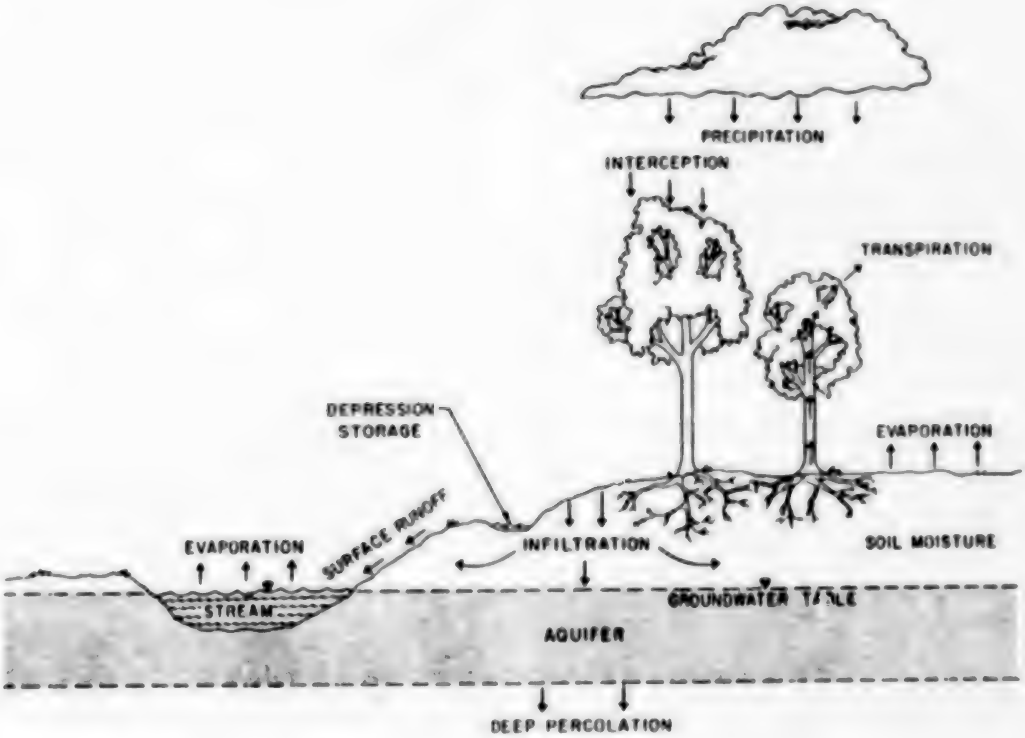


Figure 2-1. The hydrologic cycle (simplified).

encompass a wide range of precipitation events for the drainage basin. The U.S. Geological Survey installs and maintains thousands of stream gages throughout the United States. Access to information collected at these sites is available through the National Water Data Storage and Retrieval System (WATSTORE). Additionally, all Federal agencies that collect water data from streams, lakes, reservoirs, estuaries and ground waters coordinate their activities through the National Water Data Network. The computerized data system set up to identify sources of water data and types of water data these sources collect is termed the National Water Data Exchange (NAWDEX). Appendix B provides the addresses and telephone numbers to contact regarding access to both WATSTORE and NAWDEX. In the event that long-term records for a particular stream are not available, methods for estimating flows have been developed. These methods of estimating flows are based on the stream's drainage area characteristics such as size and precipitation distribution patterns in relation to similar, gaged watersheds in the region. Some of these methodologies are discussed in Chapter 4. However, due to the number of variables involved in streamflow, even long-term records of flow may be misleading, particularly if examined without considering any physical or biological changes (i.e., land use, crop rotation practices, removal of vegetation, etc.) which may have occurred or which will occur within the watershed.

In general, the hydrologic events which are of most interest are the extremes, either the minimum or maximum flows expected within a particular time period. The maximum or peak flows are usually the result of intense prolonged rainfall where the soil becomes saturated and a high percentage of the precipitation becomes surface runoff and directly enters a stream. In some regions with cool, arid climates much of the precipitation received during the year is in the form of snow. Peak flows for these areas may be linked to spring snowmelt, with the magnitude of the flow dependent on the amount of snow present and the rate at which it is released to the stream. Peak flow information is crucial to sizing structures (including new channels), stream crossings, culverts and, due to the flooding associated with peak flows, to locating buildings or other facilities near the stream. High velocities associated with maximum flows can also affect the biological stream characteristics by scouring the stream beds, uprooting bottom dwelling plants and animals, and interfering with fish movements.

Minimum or low flows in a stream are directly related to the groundwater characteristics of the watershed. Streams that receive a high contribution of groundwater may maintain flows year-round regardless of the size of the drainage area. Other streams, even with an extensive watershed may contain flows only after precipitation events due to the limited availability of subsurface water in the area. Key factors involved with the amount of groundwater that is contributed to a stream include the geologic formations of the region and the ability of the various geologic strata to hold and transmit water, and the degree by which precipitation replenishes or recharges these formations. Minimum flows are important from a water supply standpoint for domestic, industrial and agricultural use, as well as from a biological aspect, since the quantity of water in a stream is an important factor in determining the types of aquatic organisms that may be present in the stream. The most accurate estimates of minimum flows are obtained by actual long term field measurements. Minimum flows are generally expressed as the lowest flow experienced over a certain length of time that occurs once in a defined number of years. For example, the seven-day, ten-year low flow is the minimum discharge for any seven-day period that has a probability of occurring once in ten years. Flow estimations other than by direct observations may be accomplished by drainage area comparisons with streams for which low flows have been recorded, regression equations developed for a region which are also based on known flows for several streams and by observing the existing channel geometry.

Stream Forces

Water movement in streams is determined by two major types of forces. The driving force that propels the water through the channel is gravity. The opposing or resisting force is primarily the friction created between the water and the sides and bottom of the stream channel. This frictional force will vary depending on the roughness of the channel, which is based on the composition of the channel materials such as rocks, logs or other obstructions in the channel, as well as vegetation on the streambanks or growing in the channel. Other factors that affect the resistance of stream channels are the channel size and shape, the channel alignment, and the channel slope.

Formation of Natural Streams

The process of stream channel formation is influenced by climate, geology and geography. The key factors are stream discharge, resistance of land forms to erosion, geometric configuration of the stream, and the properties and amount of sediment transported (ASCE Task Committee, 1972). The evaluation of streams, termed the fluvial cycle, has been described as passing from "youth" through "maturity" and into "old age" (Lindner, 1969). The youth or initial stage consists of overland flows following fractures in rock gradually cutting a V-shaped, highly irregular, steep-sloped channel into the material most susceptible to erosion. Examples of this are mountain streams. As this process of erosion continues, the valley containing the stream is gradually widened, the stream slope or gradient is reduced and the down-cutting of the channel bottom is replaced by bank cutting. At this maturity stage, the stream is capable of transporting the material received without a buildup of sediments (aggradation) and does not erode the channel bed (degradation). Such a stream is referred to as poised or graded. Eventually the erosion process continues until the stream reaches old age, which is characterized by low relief, wide valleys and low stream gradient.

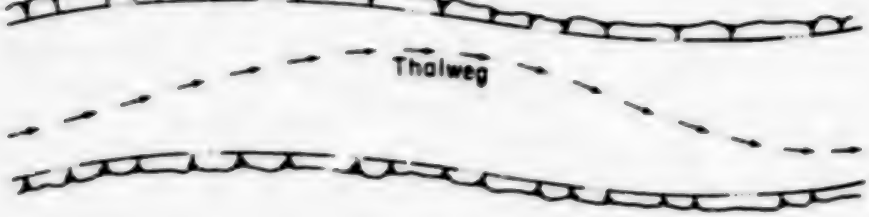
Stream Forms

There are three generally recognized forms that a stream can take -- straight, braided and meandering (Figure 2-2). The same stream may exhibit all three shapes during its course.

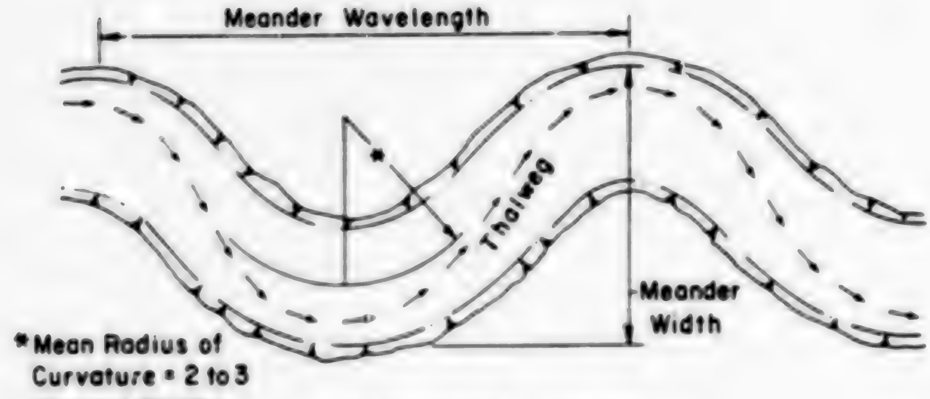
Natural stream channels are rarely straight, especially those situated in alluvial material. Although some streams appear to be straight, close examination usually reveals that the route taken by the main current, which follows the deepest portion of the channel (termed the thalweg) is sinuous. Sinuosity is measured by taking the ratio of the thalweg length to the down valley distance and is used to distinguish between straight and meandering channels. Sinuosity indices are generally in the range of one to three, with straight channels being defined as having a sinuosity of less than about 1.5 (Keefer, et al. 1980).

A more typical stream form is the meandering channel which consists of alternating curves and results in an S-shaped watercourse. In meandering streams the water has excavated deep pools on the outside of bends and has shallow crossings or riffle areas in the reach between the bends. The thalweg tends to move depending on the flow conditions in these streams. During low discharges it follows the outside of bends, crossing over at the riffle area between bends. However, during flood flow conditions where velocity is much greater, the thalweg follows a much straighter path.

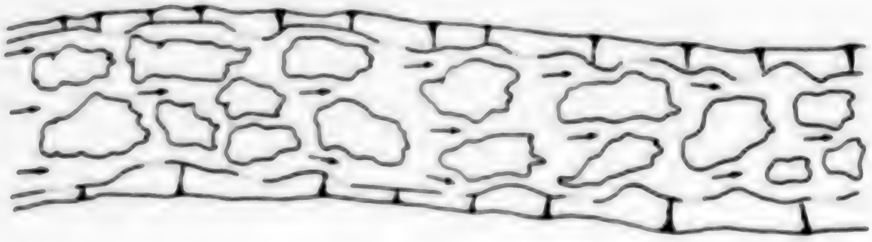
Braided streams are those in which the main channel branches cut into numerous subchannels, creating alluvial islands between their banks. A stream exhibiting this form is unstable and will readily change its course whenever flow conditions vary. Braiding indicates that an adverse



STRAIGHT CHANNEL



MEANDERING CHANNEL



BRAIDED CHANNEL

Figure 2-2. Forms of natural stream channels.

situation such as excessive sediment load, unstable banks or steep slopes in highly erodible materials exists in the stream. Due to their instability, these streams are very difficult to control from an engineering standpoint and they are often biologically unproductive.

General Relationships of Stream Parameters

Natural stream systems are dynamic, which means that their components such as discharge, velocity, cross sectional area, gradient, alignment and sinuosity are constantly changing. The interaction among these components, although observed, has not been quantified. One such observation is Lane's Principle, which states that streams strive to achieve a balance between the product of water flow and channel slope, and the product of sediment discharge and sediment size. Other generalizations include (Keefer, et al. 1980):

1. Depth of flow is directly proportional to water discharge and inversely proportional to sediment discharge.

2. The width of a channel is directly proportional to water discharge and to sediment discharge.

3. The slope of the channel, expressed as a width-depth ratio is directly related to sediment discharge.

4. Meander wavelength (Figure 2-2) is proportional to water discharge and to sediment discharge.

5. The slope of the channel is inversely proportional to water discharge, and directly proportional to sediment discharge and sediment grain size.

6. Sinuosity of a stream channel is proportional to the slope of the valley and inversely proportional to the sediment discharge.

These "rules of thumb" are not directly applicable to engineering design and vary considerably between streams and even on the same stream. They do, however, indicate that the interrelationships of stream parameters is extremely complex and that a change in one component may result in changes to the entire system.

Channel Bed and Bank Erosion

The tendency for a stream to meander, although not fully understood, appears to be a process whereby the stream adjusts its slope to the topography through which it passes, as well as to the materials comprising the bank material and sediment load through erosion of channel banks and bed (Haas, 1969). In an alluvial channel, practically all changes to the stream alignment, configuration and form are a result of sediment movement primarily by the erosion of the streambanks at bends, which causes the meanders to migrate slowly downstream (Figure 2-3). The rate at which this phenomenon occurs is based on the erosive power of the stream and the erodibility of the materials lining the channel. The erosive power of a stream is greatest during high flows when the volume and velocity of the stream water is highest. In channels consisting of erodible materials such as sand and silt, high flows may substantially alter the cross-sectional dimensions of the stream (width and depth) by eroding banks and the bed, sweeping away the finer particles and leaving the coarser, heavier sediments. These larger sediments will also move downstream, rolling and sliding along the stream bottom. The power of a stream, particularly those with a steep gradient, to move material can be considerable. Examination of mountain streams shows that they often contain large rocks and boulders which are moved downstream during high flow conditions.

In most streams, erosion will continue until the stream becomes "self-armored," reaching a point where the material underlying the channel bed is resistant to further erosion. This armor is usually overlain with fine sediment particles, but the channel is protected from further scouring

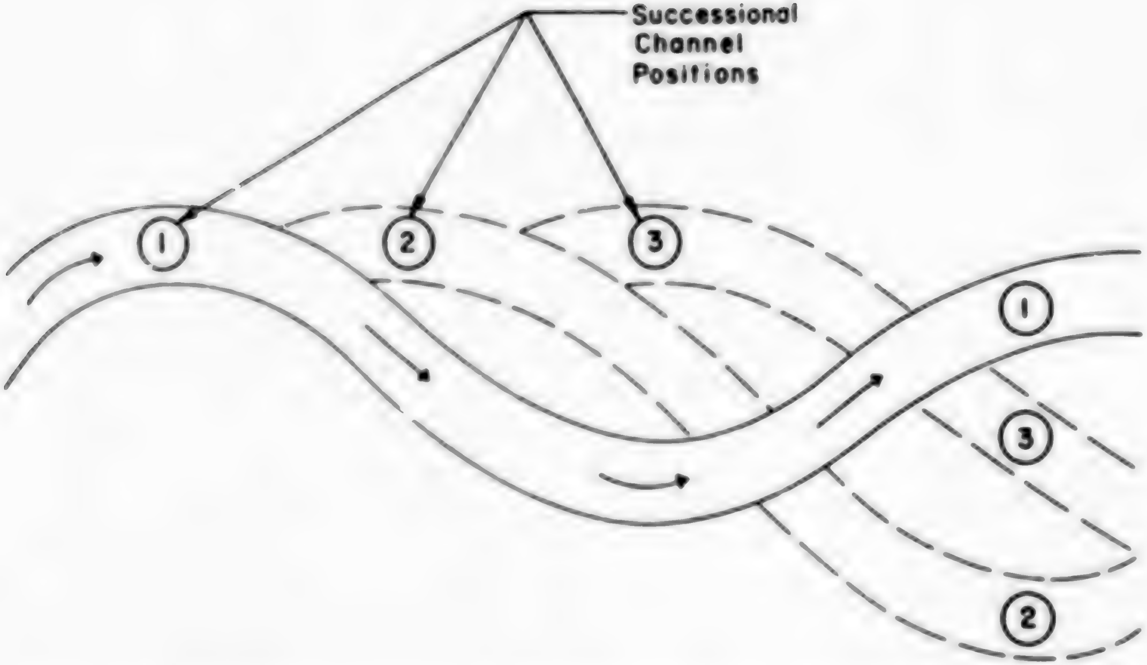


Figure 2-3. Migration of meanders in downstream direction (Adapted from Haas, 1989).

during all but extreme discharge events. Any disturbance of this armor results in continued erosion until a new layer of armor develops. Thus even if a new channel is constructed so that it closely resembles the original natural stream in area and slope, it may downcut the channel beyond the excavated depth until a non-erosive layer is reached (Federal Highway Administration, 1979).

Role of Floodplains in Stream Systems

Floodplains serve as a buffer zone for streams during high flows. Stream discharge is equal to the product of rate of flow or velocity and the cross-sectional area of the stream normal to the flow. When the stream water level rises above the confining banks, the flow spreads out, thereby substantially increasing the cross-sectional area. This results in a decrease in the velocity and a corresponding decrease in the erosive power of the stream. As the water slows down, particles settle out in the floodplain, thereby removing sediment from the stream. Floodplain vegetation also reduces velocity by increasing the resistance to flows and removing waterborne particles by trapping sediments.

BIOLOGICAL STREAM CHARACTERISTICS

Types of Organisms Inhabiting Streams

Streams can support a diverse assemblage of organisms varying from microscopic plankton to gamefish. In addition to organisms that are dependent on streams for their life requirements, numerous other plants and animals live in streams for a portion of their life cycle. One of the most comprehensive references on stream biology divides the aquatic community of streams into attached algae, vascular plants, plankton, benthic invertebrates and fishes (Hynes, 1970). Amphibians, reptiles, birds and mammals also are important components of the aquatic ecosystem and they should be considered when planning for stream alterations. Numerous references are available for gaining an in-depth description of the various types of stream organisms and their characteristics. In addition to the classic work "The Ecology of Running Waters" (Hynes, 1970) are "Freshwater Biology" (Edmondson, 1959), "Freshwater Fishery Biology" (Lagler, 1956), and "Handbook of Freshwater Fishery Biology, Volumes 1 and 2" (Carlander, 1969 and 1977). Examples of other standard texts include "Fresh-Water Invertebrates of the United States" (Pennak, 1978), "An Introduction to the Aquatic Insects" (Merritt and Cummins, 1978), "Northern Fishes" (Eddy and Underhill, 1974) and "Methods for Assessment of Fish Production in Fresh Waters" (Ricker, 1971).

Life Requisites of Stream Organisms

The four basic requirements for stream organisms are food, water, shelter and areas in which to reproduce. Of particular importance to stream inhabitants is their dependency on the adequate quality and quantity of water in the system. In a natural setting, the values of most water quality parameters measured for a particular stream during a specific season tend to fluctuate over a relatively narrow range and many of the organisms present have adapted to these conditions. Any drastic changes to the chemical composition of the water may eliminate many of the species directly and even subtle modifications to a single constituent may interfere with a particular life stage of a species, thereby eliminating it from the stream or severely reducing its chances to compete with other organisms, reproduce successfully or escape predators. Key water quality parameters include pH, temperature, dissolved oxygen, dissolved and suspended solids, nutrients, trace elements, and man-made organic contaminants (e.g., pesticides and herbicides).

The quantity of water available at any one time is equally important, particularly regarding the fisheries aspects of stream life. Minimum flows are necessary to maintain adequate depths for many fish species. In addition, diversity of flow rates (such as the ratio of riffles areas to pools) are important in providing areas for fish and other organisms to feed, rest and reproduce. A few aquatic organisms are adapted to drought conditions when only subsurface water is present, but in general these streams are of limited biological importance in comparison to those that maintain perennial flows. Flow rate or velocity also has an effect on the species present in a stream. For example, several species of sunfish and minnows prefer slow, quiet waters while characteristically, many darter and trout species require conditions that are present only in waters with higher velocities.

Stream Ecosystem Concepts

The wide variety of organisms inhabitating a stream are not isolated from each other but instead interact in a manner which creates an interdependency not only among themselves but also with the terrestrial biotic and abiotic components that exist within the drainage area of the stream. The food web concept, depicted in Figure 2-4, is one of the more critical series of interactions between the physical and biological factors that comprise the stream ecosystem because it primarily represents the energy flow in this system. The food web is important to recognize because it shows that even though organisms at various levels may not be linked directly to each other, each group performs a vital function and that if any level or group is adversely affected, the entire system can be disrupted. Often overlooked or downplayed in its role in streams (particularly in the upper reaches) is the input of terrestrial matter (referred to as allochthonous materials) such as leaves, branches and other organic debris. These materials serve as a nutrient or food supply, provide a surface for attachment by aquatic organisms, create areas for reproduction, and can be used as shelter.

The River Continuum Concept

The stream ecosystem concept relates various environmental components (i.e., sunlight, nutrients, plants, etc.) for a specific reach or stream, but does not account for changes in stream characteristics throughout an entire river system. The river continuum concept is used to describe the structure and function of biological communities in relation to the variations in physical stream factors encountered for an entire drainage basin (Vannote, et al. 1980). This river continuum concept is formulated on the basis of geomorphological principles that state that streams are in dynamic equilibrium leading to interrelationships between physical parameters (as presented previously in this chapter), which in turn influences the composition of biological stream communities. Thus, in a stream system a dynamic equilibrium of biological communities is achieved in a fashion similar to the balance of physical parameters and that this equilibrium adjusts to changes in certain geomorphic, physical and biotic conditions (Vannote, et al. 1980). Although much work remains to be done in substantiating this concept, it holds promise because it may help explain biological variations within a river system by integrating observed physical processes with biological data collected at various points throughout a particular drainage basin.

Stream Classification Systems

Streams have been classified by a number of methods. These methods have been based on a variety or combination of physical, chemical, biological stream attributes, and/or watershed characteristics. Often these systems are regional in nature and the same terms may have different definitions depending on the state or portion of the country in which the stream is located. A nationwide classification system proposed for wetlands and deepwater habitats has been adopted by the U.S. Fish and Wildlife Service (Cowardin, et al. 1979). This system utilizes ecological factors to classify water-related habitats, including streams, for use in a national inventory of wetlands and deepwater habitats. Classification by this means provides a comprehensive, descriptive

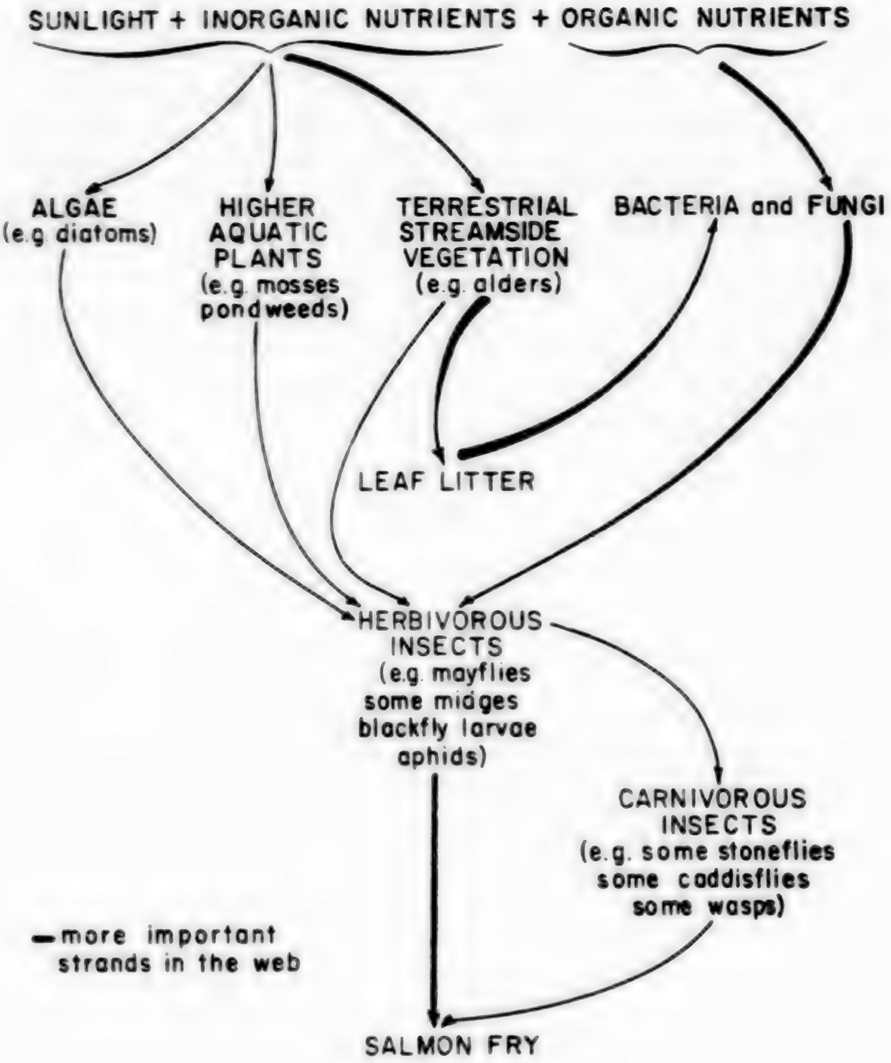

SUNLIGHT + INORGANIC NUTRIENTS + ORGANIC NUTRIENTS
ALGAE (e.g. diatoms)
HIGHER AQUATIC PLANTS (e.g. mosses pondweeds)
TERRESTRIAL STREAMSIDE VEGETATION (e.g. alders)
BACTERIA and FUNGI
LEAF LITTER
HERBIVOROUS INSECTS (e.g. mayflies some midges blackfly larvae aphids)
CARNIVOROUS INSECTS (e.g. some stoneflies some caddisflies some wasps)
— more important strands in the web
SALMON FRY

Figure 2-4. Major strands in the food web leading to salmon (Adapted from Mundie, 1974).

tool for the scientific community. The portion of this classification system that is most pertinent to streams is the Riverine System (Figure 2-5). Table 2-1 lists the factors involved in categorizing watercourses (Cowardin, et al. 1979).

A simpler, less descriptive and much broader method that relies on flow frequencies is commonly used for categorizing streams. This system divides streams into three classes:

1. Perennial or permanent streams - those streams that maintain flows throughout the year because they intercept the permanent groundwater table.
2. Intermittent streams - streams that flow during only a portion of the year when the groundwater table elevation is above the level of the stream bed.
3. Ephemeral streams - streams that flow only during and shortly after rainfalls or during snowmelt, and no permanent groundwater table is associated with the stream.

Several variations exist for defining these categories including use of drainage area sizes to distinguish between stream classes. Probably the biggest weakness in this method is that because it is based solely on flow characteristics, the amount of precipitation for a given year may determine which class a stream occupies, particularly for borderline cases.

Stream orders are another type of classification system. This system is defined as "a dimensionless measure of the position of a stream in the hierarchy of tributaries" (U.S. Geological Survey, 1977). The order of a stream is based on the number of tributaries that it has. A first-order stream has no tributaries. Second-order streams have only first-order streams as tributaries. The higher order stream extends headward to the top of the longest tributary it drains and if lengths are in doubt, the tributary with the largest drainage area is chosen. Figure 2-6 shows a hypothetical example of how this system is implemented.

The water quality of a stream can also be used as a method of classification. To ascertain the water quality of a particular stream, information on historical trends should be reviewed. The U.S. Environmental Protection Agency (EPA) operates a computerized data retrieval system, STORET, which contains water quality data collected by various state and federal agencies for thousands of streams throughout the United States. To access this information system, the regional headquarters of the EPA should be contacted (see Appendix B). Although several water quality classification systems exist, probably the most widely applied system is predicated on water use. Based on key water quality parameters such as temperature, dissolved oxygen, salinity, bacterial counts and toxic substances, an evaluation of a stream's capability to support various water uses is made. The determination of water usage may be made on established water quality standards for a particular use or it may be a value judgment on a stream's potential. The stream designation is then used as a basis for determining the quality and quantity of discharges entering the stream.

Locations on streams are generally designated by river mile. This system is initiated at the confluence of the stream, which is designated as river mile "0". Measurements then follow in the upstream direction along the mainstem of the watercourse. Thus, for example a site location at river mile 3.0 would be three miles upstream from the mouth of the stream based on the total length of the stream at that point, rather than in a straightline direction from the site to the mouth.

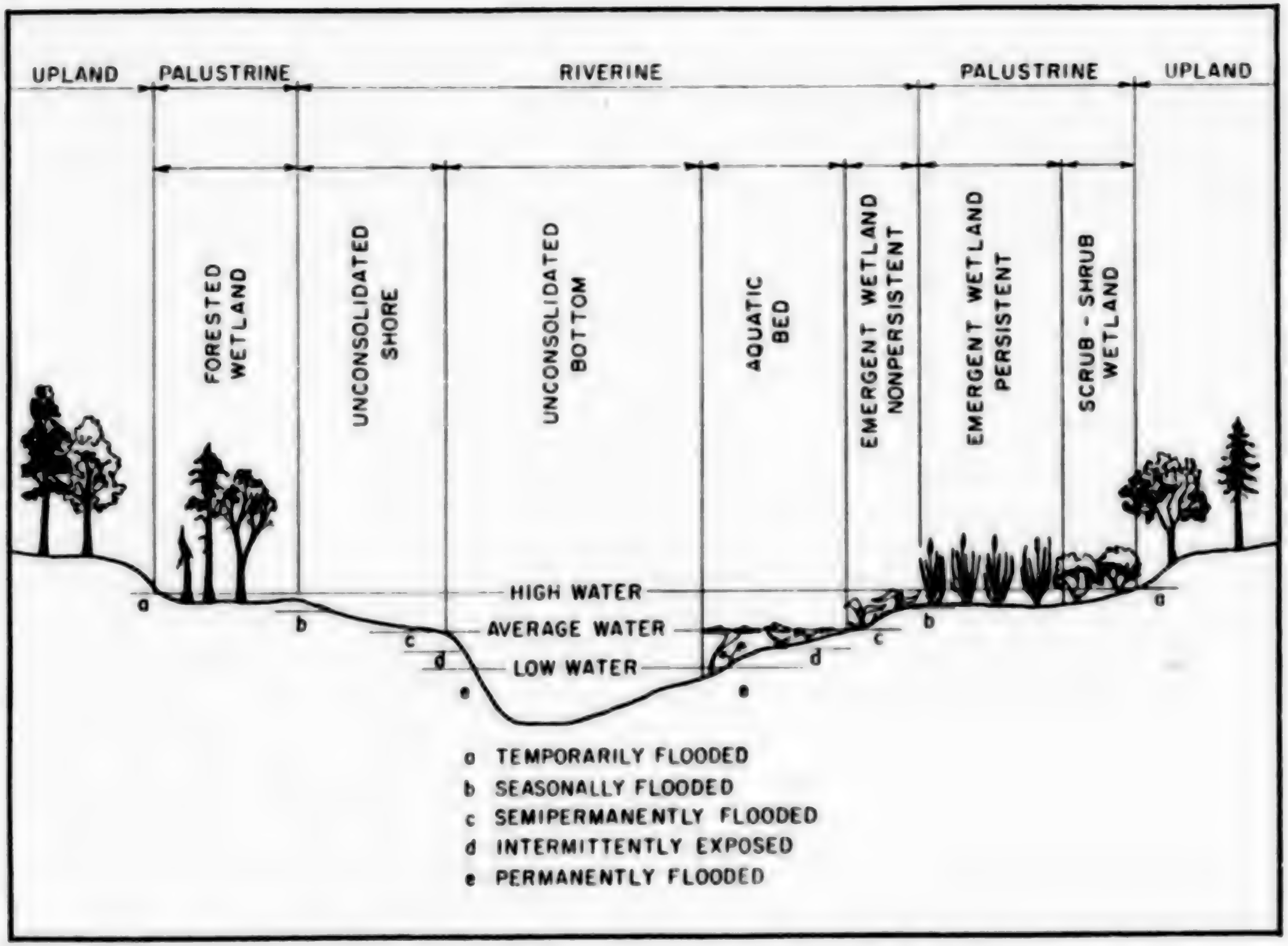


Figure 2-5. The Riverine System (Adapted from Cowardin, et al. 1979).

Table 2-1. The Riverine Classification System (Adapted from Cowardin, et al. 1979).

Riverine System Definition: The Riverine System includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 parts per thousand.

Riverine System Limits: The Riverine System is bounded on the landward side by upland, by the channel bank (including natural and man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. In braided streams, the system is bounded by the banks forming the outer limits of the depression within which the braiding occurs.

The Riverine System terminates at the downstream end where the concentration of ocean-derived salts in the water exceeds 0.5 parts per thousand during the period of annual average low flow, or where the channel enters a lake. It terminates at the upstream end where tributary streams originate, or where the channel leaves a lake. Springs discharging into a channel are considered part of the Riverine System.

Riverine Subsystems: The Riverine System is divided into four subsystems: the Tidal, the Lower Perennial, the Upper Perennial, and the Intermittent. Each is defined in terms of water permanence, gradient, water velocity, substrate, and the extent of floodplain development. The subsystems have characteristic flora and fauna. All four subsystems are not necessarily present in all rivers, and the order of occurrence may be other than that given below:

1. Tidal - The gradient is low and water velocity fluctuates under tidal influence. The streambed is mainly mud with occasional patches of sand. Oxygen deficits may sometimes occur and the fauna is similar to that in the Lower Perennial Subsystem. The floodplain is typically well developed.

2. Lower Perennial - There is no tidal influence, and some water flows throughout the year. The substrate consists mainly of sand and mud. Oxygen deficits may sometimes occur, the fauna is composed mostly of species that reach their maximum abundance in still water, and true planktonic organisms are common. The gradient is lower than that of the Upper Perennial Subsystem and the floodplain is well developed.

3. Upper Perennial - The gradient is high and velocity of the water fast. There is no tidal influence and some water flows throughout the year. The substrate consists of rock, cobbles, or gravel with occasional patches of sand. The natural dissolved oxygen concentration is normally near saturation. The fauna is characteristic of running water, and there are few or no planktonic forms. The gradient is high compared with that of the Lower Perennial Subsystem, and there is very little floodplain development.

4. Intermittent - In this subsystem, the channel contains nontidal flowing water for only part of the year. When the water is not flowing, it may remain in isolated pools or surface water may be absent.

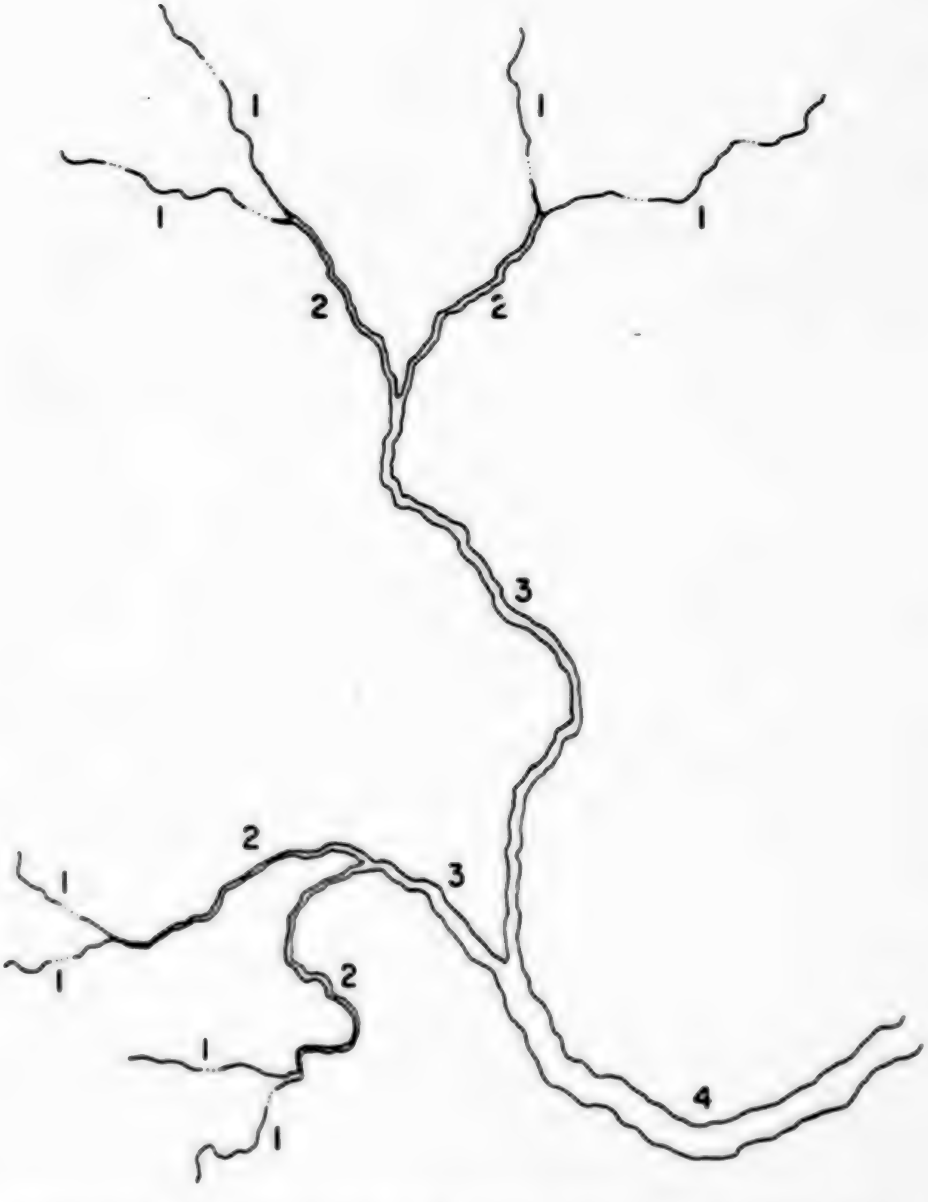


Figure 2-6. Definition sketch for stream order (From Hydrology for Engineers by R. K. Linsley, M. A. Kohler, and J. L. H. Paulhus. Copyright © 1982 by McGraw-Hill, Inc. Used with the permission of McGraw-Hill Book Company.).

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CHAPTER 3 - WHAT ARE STREAM ALTERATIONS?

The term stream alteration, as used in this document, includes either beneficial or adverse changes to streams that are a result of man-induced activities. This chapter addresses the types of activities that are considered to be alterations; where and when these alterations are typically encountered during the mining process; and how the alteration may affect the physical and biological components of a stream.

TYPES OF STREAM ALTERATIONS

During this study, three primary types of mining-related alterations were identified including physical alterations which affect the form of the stream channel; hydrologic/hydraulic alterations which change the streamflow characteristics; and water quality alterations which include the physico-chemical components of the stream.

Physical Alterations

The most obvious alterations are those direct or physical modifications to streams, that for various reasons, are performed on a stream to change its direction, realign the channel, increase channel capacity or its efficiency; narrow or constrict the channel to facilitate crossing the stream; or impound the stream to provide a water supply or to serve as a treatment for the removal of sediment. The most drastic alteration is re-routing a stream course, commonly referred to as a diversion or relocation. Stream diversions involve construction of a new channel and abandonment of the existing channel. Channel capacities are enlarged and flow conveyance efficiency improved by physically changing the width, depth and alignment of a stream through channelization; by removing sediment deposits during dredging operations; or, by clearing and snagging, which involves removing obstructions from the stream. Generally accompanying these types of channel changes is another physical alteration which involves removal of streambank vegetation to gain access to the stream for the equipment.

Stream crossings constitute a somewhat different type of alteration because instead of directly affecting entire reaches or sections of a stream such as in a relocation or channelization project, stream crossings are usually limited to a narrow disturbance perpendicular to the flow. The location of crossings are often based on sites where the stream naturally converges. When structures such as bridges and culverts are to be constructed, fill material is used to narrow the channel.

Impounding or damming streams refers to the process whereby water is stored or flow impeded by a structure that spans the stream perpendicular to the flow. In this document discussion of such structures will be limited to small or low-head dams used primarily to slow the water and allow sediment to settle, or dams used as fish habitat improvement devices to create pools.

Hydraulic/Hydrologic Alterations

Hydrologic and hydraulic alterations are defined herein as actions that affect the natural variations in flow of the stream or that change the stream channel capacity to convey those flows. As explained in the section addressing the hydrologic cycle, the interaction of a stream and its flow characteristics with the features of its drainage area means that any disturbance in a watershed may result in changes of discharge rates into the stream. For example, removal of a substantial portion of the vegetation within the drainage area decreases the interception capacity of the cycle. The amount of water retained as interception by vegetation during small storm events may account for a substantial portion of the annual rainfall (Linsley, et al. 1982). Thus, if the vegetative cover is removed, more of the rainfall reaches the ground and consequently enters the stream through surface runoff and groundwater interflow processes. Conversely, activities that increase the drainage area's infiltration capacity or depression storage may, in turn, affect a stream's response to storm events, diminishing the amount of water reaching the stream or lengthening the time when the stream attains its maximum flow. Minimum flows can also be substantially altered by excavation and earthmoving activities, leading to disruption of groundwater movement or increasing or decreasing the quantity of precipitation that infiltrates to the groundwater table. Such disturbances could potentially lower the water table and change a perennial stream into an intermittent stream or limit flow in a stream bed to storm-related events.

Modifications to the watershed topography can also substantially alter streamflows by directing runoff from one watershed into a stream in another watershed. This type of alteration can potentially eliminate one stream while at the same time, causing other streams to exceed their normal capacities, potentially resulting in flooding and severe erosional problems until a larger stream channel is formed.

The relationship of stream parameters including discharge, slope, velocity, sediment, and bed load determines the cross-sectional area and therefore the capacity of a natural stream. Variations occurring to these parameters may result in sediment deposition (aggradation) in the channel, downcutting (degradation) and/or an increase in streambank erosion. For example, construction or other disturbances within a drainage basin will commonly change the amount of sediment transported by runoff into the stream. A temporary increase in the sediment load may cause localized aggradation that is usually flushed away during the next flood or high velocity occurrence. Long-term increases in sediment input will result in the formation of gravel or sand bars which in turn will decrease the effective depth of channel. The stream will then have a tendency to become wider to maintain its original capacity to convey high flows.

Water Quality Alterations

Changes to the water quality of a stream generally occur as a result of newly created discharges to a stream, either in a concentrated, clearly defined form such as an industrial outfall (termed a point source) or as a result of materials such as soil particles transported by surface runoff which may enter the stream throughout its length (nonpoint source). Other sources of potential water quality alterations include groundwater seepage, rainfall, erosion and/or dissolution of the materials comprising the channel bed and banks, and removal of the streamside vegetation.

Although variations in water quality occur naturally due to weathering of different geologic strata and climatic conditions, most changes can be attributed to man's activities within the watershed. Some of the more common alterations to stream quality due to the influence of man are:

- Elevated concentrations of suspended solids and turbidity from operations that expose erodible soils.

- Changes to pH, acidity and alkalinity through the entry of substances such as acid mine drainage.

- Increased levels of dissolved solids, generally some combination of calcium, magnesium, sodium, potassium, chlorides and sulfates, from such sources as industrial and municipal wastewater, mine drainage, irrigation return water, or urban runoff.

- Increased nutrients (primarily phosphorus and nitrogen) from agricultural fields, municipal wastewater discharges, etc.

- Introduction of trace metals like mercury, lead, cadmium, arsenic, selenium, copper, and zinc which are normally found in only minute concentrations in natural waters. Other metals such as iron and manganese are associated with geologic formations and therefore generally occur in higher concentrations than trace metals in stream waters. However, industrial wastes and mine drainage may result in an increase in concentrations of these elements well above ambient values.

- Loss of vegetation along streambanks will generally create increased exposure to light and wider fluctuations in water temperature.

- Concentrations of dissolved oxygen will vary depending on changes to water temperature, turbulance causing aeration in the stream, and atmospheric pressure as well as changes to the rate of photosynthesis, respiration and decomposition of the biologic community. Alterations to dissolved oxygen concentrations may be artificially induced by increasing water temperatures and introducing substances such as sewage or some types of industrial wastes that have a high biochemical oxygen demand (BOD) or chemical oxygen demand (COD).

- Entry of oils, grease, pesticides, herbicides and other organic compounds will also alter the water quality of streams. Sources of these substances range from urban areas to farmlands.

STREAM ALTERATIONS AND COAL MINING

Under the two broad categories of surface mining and underground mining, there are basically five main phases in a mining operation (Moore and Mills, 1977). These phases are: (1) exploration, (2) mine development, (3) mine production-extraction activities, (4) mine production-ancillary activities, and (5) reclamation. Table 3-1 outlines the major activities associated with each of these phases that can affect streams.

Based on the authors' observations and those presented in several reference works, any of the three major categories of stream alterations (physical, hydrologic/hydraulic and water quality) can occur during each of the five phases of mining (Cook, 1979; Grim and Hill, 1974 and 1972; and Moore and Mills, 1977). The following discussion is limited to the most common types of stream alterations, bearing in mind that site-specific conditions such as the size of the operation, topography, climate, and mining methods utilized as well as the care taken in their implementation, determine the type and extent of the alterations.

Exploration

Temporary stream crossings and in particular, fording streams with heavy equipment, are the major physical alterations expected during coal exploration. Changes in water quality, primarily increased suspended solids and turbidity, are generally associated with road construction and localized clearing operations necessary to access drill sites.

Mine Development

Construction of surface facilities including buildings, roads, utility right-of-way corridors and refuse disposal areas is accompanied by the same water quality impacts associated with any large scale construction project. The most obvious effects to water quality include the short-term elevation of suspended solids and turbidity. Siting of roads, railroads, refuse disposal areas, and surface facilities for mines in hilly or mountainous terrain may often require that streams be diverted, straightened, crossed, culverted or some combination thereof because the stream valleys often provide the only feasible area in which to construct these facilities.

Mine Production - Extraction

Underground mining as regulated under the Surface Mining Control and Reclamation Act of 1977, has a limited potential for affecting streams. The major potential alterations are water quality degradation from mine dewatering discharges, water infiltration into mine workings situated beneath streams, and lowered groundwater tables which reduces the base flow of streams.

Table 3-1. Coal mining activities (Adapted from Moore and Mills, 1977).

1. EXPLORATION
    - a. Surveying
    - b. Test Drilling --
        temporary access roads, drill pad construction, drilling operations, reclamation
    - c. Test Mining --
        haul roads, excavation, reclamation

2. MINE DEVELOPMENT
    - a. Construction of Beneficiation Facilities
    - b. Construction of Transportation Facilities --
        railroad, access roads, haul roads
    - c. Construction of Support Facilities --
        buildings, parking lots
    - d. Construction of Utilities --
        electric transmission lines, water supply (wells, dams, pipelines)
    - e. Construction of Disposal Facilities --
        septic tanks, sediment ponds, runoff controls, slurry ponds, refuse areas

3. MINE PRODUCTION (Extraction Activities)
    - a. Operation of Machinery and Equipment
    - b. Removal of Surface Features
    - c. Topsoiling Material Storage
    - d. Dewatering
    - e. Blasting
    - f. Overburden Removal
    - g. Overburden Disposal
    - h. Mineral Extraction

4. MINE PRODUCTION (Ancillary Activities)
    - a. Operation of Beneficiation Facilities --
        storage, crushing, cleaning, loading
    - b. Operation of Transportation Facilities --
        railroad, access road, haul road, conveyors
    - c. Operation of Support Facilities --
        fuel and chemical storage, maintenance yards, parking lots, sewage treatment plants
    - d. Operation of Utilities --
        electric, water supply
    - e. Operation of Disposal Facilities --
        septic tank, sediment pond, runoff controls, slurry ponds, refuse areas

5. RECLAMATION
    - a. Operation of Machinery and Equipment
    - b. Backfilling and Grading
    - c. Topsoiling and Revegetating
    - d. Irrigation

Surface mining as opposed to underground mining has a greater potential for creating stream perturbances since it requires substantial earthmoving and handling. The type of contour mining found in the Northern Appalachian coalfields is generally conducted in the headwaters of first- and second-order streams. In some instances, first-order streams (those with no tributaries) must be diverted around the highwall. This affects drainage patterns by combining several small streams and routing them together with surface runoff through or around the minesite area. Depending on the regional characteristics of the seam being mined, these operations may also be associated with acid mine drainage. Such operations require special handling and placement of acid-forming overburden as well as elaborate and often costly pit dewatering and treatment schemes. Mountaintop removal operations generate large volumes of overburden, presenting possible problems with elevated suspended solids concentrations in receiving streams resulting from storm event runoff. Mountaintop removal may also require segregation and burial of toxic or acid forming materials. In addition, since mountaintop removal operations occur at the drainage divide of watersheds, runoff patterns may be substantially altered.

Midwestern coal mines are characterized by large area mining operations using draglines, truck and shovel operations, scraper/bulldozer, and bucket wheel excavators. Economic and equipment constraints make many of the operations impractical unless streams are diverted so that the mining sequence can proceed without major interruption and loss of coal reserves. Disturbance of large areas also temporarily disrupts the infiltration-runoff and evaporation-transpiration portions of the hydrologic cycle.

In the semi-arid climate in which many of the western mines are located, it may be necessary to divert ephemeral and intermittent streams during the life of the operations for area and open pit mines. Regulatory concerns in western mining states are primarily centered around increased suspended and dissolved solids and the disturbance of any alluvial aquifers which may be associated with mining through streams.

Mine Production - Ancillary Activities

Water quality alterations are the most sensitive issues regarding the operation of support facilities for coal mining. Runoff from haul and access roads, mine yard areas and refuse disposal sites, although regulated by state or federal wastewater discharge (NPDES) programs, potentially can affect streams if proper control and treatment is not implemented.

Reclamation

During the reclamation phase of mining, large earthmoving and handling operations can result in temporary water quality alterations until vegetation is established or other soil stabilization practices are completed. Final land configurations may differ from pre-mining topography thereby changing drainage patterns. It is also during this phase that temporary stream diversions are returned to their original or permanent diversion channels. In order to augment revegetation during the initial phase of reclamation, some irrigation practices may be necessary on a temporary basis. In this event, less water is available for streamflow. These actions are generally short-term and if proper reclamation techniques have been implemented, the potential for permanent stream alterations is limited.

POTENTIAL EFFECTS OF STREAM ALTERATIONS

The effects of stream alterations have been extensively studied. Although most of the efforts have concentrated on channelization impacts, results of these studies are, in general, applicable to the physical alterations experienced as a result of mining. The U.S. Fish and Wildlife Service, National Stream Alteration Team funded several projects that dealt with the effects of channelization (Arner, et al. 1976; Bulkley, et al. 1976; Dodge et al. 1976; Frederickson, 1979; Griswold, et al. 1978; Headrick, 1976; Lund, 1976; Menzel and Fierstine, 1976; Parrish, et al. 1978; Schmal and Sanders, 1978; Witten and Bulkley, 1975; Zimmer and Bachmann, 1978). Other excellent references on effects of channelization have been completed by Simpson, et al. (1982), Wydoski and Helm (1980), Keller (1976), and Shields (1981). The impacts of mining on streams and aquatic organisms have been reported by Branson and Batch (1974 and 1972); Matter and Ney (1981); Letterman and Mitsch (1978); Leedy (1981); Vaughan, et al. (1978); Gore and Johnson (1979) among others. Reports covering specific stream alterations and their effects include Marzolf (1978) for clearing and snagging operations; Gerke and Cantor (1981) for coal dredging impacts; and, Stern and Stern (1980 a and b) for bank stabilization effects. The effects of stream alterations on riparian areas have been addressed by Teskey and Hinckley (1978 a, b and c; 1977 a, b and c), Walters, et al. (1980 a and b), Karr and Schlosser (1977), and Barclay (1980).

The purpose of this document is not to recount the findings of the aforementioned documents, but rather to present the major impacts associated with particular alterations. For ease of discussion, the effects are divided into those affecting physical stream characteristics and those which deal with the biological components of streams.

Physical Effects

Physical alterations to stream channels can usually be related to changes in current velocity or in the cross-sectional area of the stream. Other alterations may originate from altering stream lengths by realigning the channel or by increasing peak flow quantities that the stream must handle. The resulting physical impacts include:

- scouring of stream beds and banks,
- increased or decreased stream gradient,
- the potential to increase downstream flooding if only a section of the stream's capacity has been improved,
- increased sediment load from erosion of channels that are not stable,
- less diversity in the stream's vertical profile (pool:riffle sequence),
- where a streambed has been lowered, tributary channels will erode their beds in an upstream fashion in order to adjust to new confluence elevation, and
- as a result of new or hydraulically improved channels, there may be increased downstream sedimentation as a result of a decrease in velocity as the water leaves the more efficient channel.

Fish and Wildlife Effects

Table 3-2 lists the effects associated with four main categories of stream alteration consequences to the biological community. This table is not all inclusive, nor is it applicable to all types of alterations, but it does indicate that a wide variety of adverse biological impacts can be created from stream alterations due to the interactive components which comprise an aquatic system, particularly a stream community.

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Table 3-2. Summary of fish and wildlife consequences of stream alterations.

1. EFFECTS OF CHANGES ON THE PHYSICAL DIMENSIONS OF STREAM CHANNELS
   - a. Inadequate low flow depths for fish survival
   - b. Loss of refuge areas for aquatic biota during high velocity events
   - c. Decrease in vertical habitat diversity (pool:riffle sequence)
   - d. Stream shortening often reduces available habitat (quantitatively and qualitatively)
   - e. Flow depth increase in channels routed through incline or final cut lakes, changing habitat from lotic to lentic

2. EFFECTS OF STREAMSIDE CLEARING
   - a. Increased water temperature, decreased dissolved oxygen
   - b. Reduction in terrestrial energy input (allochthonous materials)
   - c. Debris input reduction lessens fish cover
   - d. Loss of filtering capabilities of vegetation to trap sediment and nutrients
   - e. Loss of riparian habitat essential for numerous species of birds, mammals, reptiles and amphibians
   - f. Increased soil erosion
   - g. Interference with migration and movement of wildlife along stream

3. EFFECTS OF SILTATION AND TURBIDITY
   - a. Mortality of fish eggs and fry
   - b. Smothering of sessile organisms
   - c. Reduction in primary production
   - d. Instable substrate/loss of substrate variety
   - e. Reduction in dissolved oxygen from organic sediment decomposition
   - f. Shift in species composition
   - g. Interference with respiration of aquatic organisms
   - h. Interference with sight feeders

4. EFFECTS OF MINE DRAINAGE
   - a. Direct (acute) consequence of pH, acidity/alkalinity, toxic metals
   - b. Smothering from precipitation of iron hydroxides
   - c. Indirect (chronic) chemical changes resulting in spawning interference, egg and fry survival, predator-prey relationships, avoidance reactions of fish, bioaccumulation
   - d. Reduction in stream dissolved oxygen if mine drainage is not fully oxidized before entry (BOD and COD)

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CHAPTER 4 - STREAM PROTECTION MEASURES

This chapter addresses the engineering and water quality procedures that, if properly implemented, will help protect or preserve the major stream characteristics or minimize the effects from mining-related stream alteration situations. Five main areas of concern are covered as individual sections, beginning with Section 4.1, stream diversions including both temporary and permanent relocations of ephemeral, intermittent and perennial streams. Section 4.2 addresses situations when stream channel capacities have to be increased, generally for flood control purposes or protection of near-stream structures. Section 4.3 discusses stream crossings for haul and access roads. Stream impoundments, addressed in Section 4.4, can affect downstream flow conditions, either through reducing release rates or by increasing evaporation, but may also be beneficial as evidenced by situations where streams have been routed through final cut lakes and downstream quality has improved. Section 4.5 briefly discusses water quality degradation prevention techniques to control erosion and sedimentation, and instream techniques applied to treating mine drainage.

4.1 - STREAM DIVERSIONS

Stream diversions, relocations, or re-routings are terms used to describe a stream which has been moved from its original course and into a preselected direction. These disturbances are probably the most challenging, environmentally disruptive and certainly most complex of the stream alterations to be discussed in this document. The approach taken in this section is to present a logical sequence of steps that can be followed to plan, design and implement a stream diversion project, with the emphasis on the engineering aspects. Habitat improvement measures are addressed in Chapter 5, but will be included in this chapter where appropriate for consideration in the planning and design of new channels. Several key qualifications and simplifications have been made to limit this section to a manageable size. The following paragraphs cover these points.

The first qualification is that throughout this section the emphasis is placed on re-creating or imitating natural streams when designing a stream diversion. However, due to the complex nature of streams, the accurate prediction of the consequences of this approach has not been performed with a high degree of certainty. Thus, future developments in this field may better define a more exact process, but to date the design procedures for the relocation of streams that include such things as meanders are more of an art than a science.

The second qualification is that stream diversions require site-specific information and study before being implemented; thus only generalized procedures are presented. Numerous combinations of factors need to be considered and even addressing basic categories (temporary vs. permanent; perennial vs. intermittent vs. ephemeral; Eastern U.S. vs. Midwestern U.S. vs. Western U.S.; high gradient vs. low gradient) separately is beyond the scope of this project. However, regardless of these variations, the approach is similar, differing primarily in the level of detail and site-specific data required to plan and design a relocation project.

The third qualification is that the reader has at least a rudimentary knowledge of the basic principles involved in subjects such as surface and groundwater hydrology, open channel hydraulics, geology and aquatic ecology. It is not possible in this text to develop the theories and underlying assumptions involved in the general statements to be presented in each of the procedures discussed. It is extremely important to realize that a number of different disciplines must be involved in these types of projects. Persons with backgrounds and technical expertise in hydrology, hydraulics and geotechnical engineering as well as stream ecology should have input to the design along with the mine planners and construction engineers responsible for implementing the project.

The fourth and final point is that state and federal programs which regulate the mining of coal are subject to change. Any use of specific criteria would only serve to confuse the issue and date the material contained in this document; thus no reference is made to any regulations or statutes. Numerous contacts and site reviews have been made with governmental agencies as well as with coal operators and an attempt has been made to include their suggestions and recommendations.

The following material is subdivided into the major steps that have proven successful when diverting a small stream. To facilitate cross referencing in the remaining portion of the document, these major steps are numbered sequentially as follows:

4.1.1 Identification of the Need to Divert a Stream
4.1.2 Baseline Inventory of Existing Stream Characteristics
4.1.3 Selection of a Preliminary Corridor
4.1.4 Determination of the Design Discharge
4.1.5 Determining Channel Geometry
4.1.6 Channel Alignment
4.1.7 Channel Bed and Bank Linings
4.1.8 Streambank Stabilization
4.1.9 Channel Transition Zones
4.1.10 Alternative Channel Designs
4.1.11 Controlling Stream Access
4.1.12 Construction Practices During Stream Channel Relocation Projects

The overall goal of a stream diversion as discussed in this section is to produce a "stable" channel which will contain diverse habitats within the newly relocated stream. A stable channel in this instance is one that is not excessively eroding the bank or stream bed, and has the capacity to convey the design storm. One of the primary considerations and purposes of a stream diversion is to convey water away from or around a disturbed area and to produce a stable channel as quickly as possible. An unstable channel will not only neutralize any attempt to improve habitat, within the stream reach, but will also adversely affect conditions both upstream and downstream from the diversion.

4.1.1. Identification of the Need to Divert a Stream

The need to divert a stream during the life of a surface mine should be fairly evident to a mine operator, given the position of the coal seam, overburden depth, equipment and topography at the mine. Recognition of the necessity to divert due to the development of surface facilities such as haul and access roads may be more difficult. This decision needs to be made as early as possible during the planning phase of mining for a variety of reasons, but primarily to allow enough lead time for the permitting process. Long delays have occurred to mining operations that have planned major stream diversions. These delays are due in large part to changing regulations, but also to in-house engineering and design time requirements, and uncertainty between agencies and operators regarding the handling of the diversion.

Another factor that can influence a stream alteration project is the time required to obtain approval from the responsible regulatory agency. This includes identification of the necessary permits and early interaction with the appropriate agencies. Possibly the best process to follow is that once the need for a diversion is determined by the operator it should be followed by a sincere attempt to identify all of the local, state and federal agencies which are responsible for issuing permits or commenting on permit applications. Once these parties are defined, a meeting should be arranged and, if possible, representatives from each agency should meet to discuss the available project alternatives. The benefits derived from such a meeting are twofold. First of all, the agencies will be able to gain a better understanding of the project from a thorough explanation of the situation and, secondly the operator should benefit from identifying various agencies' concerns early in the process. The potential problem of conflicting requirements between various agencies should also be addressed. Establishing a good rapport between operator and agencies must be followed by continued flow of information between these parties so that a mutually agreeable solution is reached.

The amount of interaction required for a diversion project will be related to the type of stream. Relocation of ephemeral or intermittent streams are generally not regarded to be of as much concern as perennial streams. However, these facts need to be established early in the mine planning and permitting process.

4.1.2 Baseline Inventory of the Existing Stream Characteristics

Collection and use of information on the existing stream can improve both the design and ecological effectiveness of a substitute channel. The most acceptable and, with the exception of rigidly lined channels, possibly most stable channels are those that imitate the shape, length, and gradient of the original channel. Although the level of effort necessary to establish existing stream conditions should be commensurate with the stream's "importance" (based on safety and ecological criteria), pre-diversion engineering and ecological data collection is necessary to determine the subsequent level of detail for the design of the new channel. Thus, thoroughly defining existing conditions may lessen the work and data required in the succeeding stages of the project.

Pre-diversion studies consist of a combination of collecting published information on the stream and conducting field reviews. Monitoring programs should be established on the stream if insufficient data exists to characterize the stream.

The following types of data collection for pre-diversion activities were compiled from several references and discussions with mine operators as well as with state and federal agencies responsible for reviewing stream relocation projects (Shields, 1981; Soil Conservation Service, 1977; Virginia State Water Control Board, 1979; Davis, 1975).

a. Geomorphologic History of the Basin.

The purpose of gathering information on this subject is to ascertain the present stability of the stream based on its history. Some basic questions need to be answered. Is the stream "graded or poised," meaning that is the stream in an equilibrium where the sediment input is balanced by the stream's ability to transport the sediment? Some streams are in a downcutting phase where the channel bed is being incised either because of recent disturbances in the basin or simply because it is a relatively new stream based on a geologic time scale. Is the stream subject to severe meandering? Are new meanders being readily formed and old meanders being cut off? What types of sediment deposits are found in the stream valley? Has the stream had a past history of severe flooding? Have any other changes to the stream or nearby stream been performed and if so, what were the results? This type of information may be found in geologic reports, local university libraries, state geologic agencies or even through discussions with local representatives of state or federal agencies and long-time residents in the area.

b. Obtain Mapping of the Area.

To determine the extent of the drainage areas at various points along the stream and to get an overview of the relationship of the stream with its tributaries and the overall drainage pattern of the area, a USGS 7-1/2 minute topographic quadrangle map should be consulted. The topographic maps may be obtained from local commercial map dealers, or directly from the U.S. Geological Survey. Current aerial photographs can be compared with any past aerial photos to identify recent changes in the watershed. From recent aerial photos a better feeling for the channel alignment, the frequency and uniformity of meanders and a more accurate measurement of channel length can be gained than from topographic maps. Aerial photography is normally taken by mining companies prior to developing the mine to serve as a basis for preparing detailed topographic maps of the site. In the event aerial photography is not readily available, the local Soil Conservation Service office, the state agricultural extension office or the local Agricultural Stabilization and Conservation Service office can be contacted to determine if they have any aerial photographs of the area under consideration.

c. Perform a Hydraulic Analysis of the Stream.

The level of effort expended for this step requires some judgment on the part of person performing the study because there are various techniques available for determining flood flows and flood elevations. Some techniques are simple approximations using standard or regionalized formulae and information taken solely from topographic maps, while others require field surveys and complete simulation models. Generally the latter method is reserved for projects dealing with perennial streams and the former is used when addressing small intermittent or ephemeral channels. Regardless of the methodology selected, this analysis should be performed by a qualified person such as a hydraulic engineer. Information that should be generated includes flood discharges and corresponding elevations for events ranging from the 2-year flood up through the 100-year flood (usually at the interval of 2, 10, 25, 50 and 100-year events).

d. Conduct a Field Review of the Stream.

A field review may be performed in conjunction with the hydraulic analysis to estimate floods. Again the field review can be a formal, in-depth study or a brief walk-over of the site, depending on the stream in question. Several parameters should be measured or noted in either case.

- Channel Geometry (Width, Depth, Bank Slope) - The cross-sectional area of the stream, defined by the width, depth and slope of the banks is a key factor since the new channel should be able to handle about the same discharge as the original stream. From the topographic mapping and visual observations, the stream should be divided into sections in which the channel slope and geometry are similar. These sections are referred to as reaches. For each reach within the length of stream to be affected, the width, depth and bank slopes of the channel should be measured.

- Estimation of Manning's 'n' - One of the most accepted methods for estimating stream velocities under various conditions is through the use of Manning's Formula:

$$V = \frac{1.49}{n} R^{0.67} S^{0.5}$$

where V is the mean velocity in feet per second (fps), R is the hydraulic radius (ratio of the cross-sectional water area to its wetted perimeter) in feet, S is the slope of the channel and 'n' is the empirical coefficient of roughness, known as Manning's 'n'. Manning's Formula is related to stream discharges by the continuity equation

$$Q = VA$$

where Q is stream discharge in cubic feet per second (cfs), V is mean velocity in fps, and A is the cross-sectional area of the flow in the channel, measured normal to the direction of flow in square feet. Combining the two equations

$$Q = \frac{1.49}{n} AR^{0.67} S^{0.5}$$

This allows the designer to approximate channel capacities to handle discharges if the channel slope and geometry are known along with the coefficient of roughness 'n'. The following describes the selection of an "n" value:

> "At the present stage of knowledge, to select a value of 'n' actually means to estimate the resistance to flow in a given channel, which is really a matter of intangibles. To veteran engineers, this means the exercise of sound engineering judgment and experience; for beginners, it can be no more than a guess, and different individuals will obtain different results" (Chow, 1959).

The 'n' value in a stream will vary not only with location but also according to depth of flow and the type and extent of vegetation, both of which change with time. Several other factors that are also important include variations in channel cross-section, alignment and obstructions. Many techniques have been utilized to estimate 'n', but the most common methods are probably the use of standard tables and pictures describing channels with various conditions, as presented in Chow (1959), or the color photographs contained in the U.S. Geological Survey Water-Supply Paper 1849 (Barnes, 1967). Natural streams may have 'n' values that range from 0.025 to as much as 0.150 (Chow, 1959). With all the extreme variations that are associated with this technique, one can see that if Manning's Formula is to be used in design, there is no real substitute for experience when estimating 'n' for a particular reach of a stream.

- Channel Bed and Bank Conditions - In conjunction with an estimation of flow conditions, the stability of the stream bed and banks should be examined. Any evidence of bank caving, slumping or undercutting should be noted, along with the composition of the materials in the stream bed and banks. Channel bed composition or substrate is commonly classified by particle size as follows:

clay	0.004 mm
silt	0.004 to 0.06 mm
sand	0.06 to 2 mm
gravel	2 to 64 mm
rubble or cobbles	64 to 256 mm
boulders	256 mm

The substrate description would typically be given as a percent composition breakdown of the above categories.

Any other anomalies or discontinuities about the stream or its stability, such as tributary headcutting or excessive sedimentation may also provide useful information during the design of the new channel.

e. Prepare Drawings of the Existing Channel Conditions.

The level of detail in the design drawings is related to the type of project under consideration. Design drawings of perennial stream relocations would probably include plan views of the stream, profiles of the channel bed and water surface under different discharge conditions as well as cross-sections of the channel and floodplain taken within each representative reach. Intermittent and ephemeral stream diversions may not require this level of detail to adequately represent existing conditions.

f. Ecological Baseline Monitoring.

For perennial streams of high quality and those streams for which no baseline (background) information is available, sampling of biological and water quality parameters may be necessary to characterize the stream. This information will also provide an indication of the success of the recolonization in the new channel by aquatic communities when the stream is diverted. The necessity of ecological monitoring should be determined early in the project because quantitative assessments of baseline conditions may require six months to a year or even longer to complete. The two most frequent components of the aquatic stream system that are sampled to establish baseline conditions are fish and macroinvertebrates. Fish are important from an economic and recreational standpoint. Aquatic macroinvertebrates are large enough to be seen by the unaided eye and can be retained on a U.S. Standard No. 30 sieve (Weber, 1973); they live at least part of their life cycles within or upon substrates in a body of water or water transport system and they are generally considered to be good indicators of water quality.

There are two major reasons for using macroinvertebrate communities to monitor stress caused by the introduction of contaminants into an aquatic system. These characteristics include:

1. Benthic organisms have limited mobility and relatively long life spans. Therefore their condition is a reflection of occurrences during the recent past, including the introduction of sporadically discharged wastes that would be difficult to detect by periodic water quality sampling.

2. Benthic organisms tend to concentrate and retain certain substances such as pesticides, radioactive materials and metals which may be discharged periodically or occur at low levels in the water. Such substances can be detected by chemical analysis of particular invertebrate groups.

Another factor which makes macroinvertebrates ideally suited for monitoring stream conditions is the specialized nature of certain species. Invertebrates have evolved in such a way that the composition of a benthic community is largely determined by physical characteristics such as the flow patterns in a stream and the type of channel bed material or substrate. Changes to these physical factors will result in changes to the species composition of the stream. Thus, periodic inventories of the types of macroinvertebrates present provides an indication of changes that may have taken place to both water quality and physical parameters between sampling periods.

The general steps involved in an ecological survey are as follows (It should be noted that each of these steps should be fully documented for future reference and to enable the studies to be repeated if required):

- Purpose of the Study - Defining the objectives clearly is necessary in developing the scope of the study. Is the study to characterize the stream, to quantify the biological productivity of the stream, to identify all stream inhabitants or for use as a comparison after implementation of a project?

- Study Design - Based on the objectives, a level of effort is defined and a sampling program developed. Such questions as what should be sampled, how frequently and for how long need to be addressed. An acceptable sampling methodology must also be determined.

- Sample Collection and Analysis - This includes the field sampling and the analysis of the collections either in the field or laboratory. This step will also include sample preservation, handling and storage.

- Data Analysis and Interpretation - Once the samples have been analyzed, the data generated must be compiled and tabulated. Depending on the effort determined by study objectives, the data are examined either statistically or qualitatively and some interpretation of the results must be made.

For the overall biological aspects of baseline monitoring, the reader should examine both "A Systems Approach to Ecological Baseline Studies"

(States, et al. 1978) and "Biological Field and Laboratory Methods..." (Weber, 1973). A rapid procedure has been developed for assessing biological conditions by surveying benthic organisms without the expense, time and expertise required to identify each organism to species (Mason, 1979). Two widely used baseline water quality references that address methods of collection, handling and analysis are "Standard Methods" (American Public Health Association, 1980) and "National Handbook of Recommended Methods for Water-Data Acquisition" (U.S. Geological Survey, 1977). A five volume set entitled "Water Quality Manual" and prepared for the Federal Highway Administration (1976), which addresses water sampling and data analysis, can be of benefit to those who may be unfamiliar with water quality surveys because it provides justification for the procedures to be followed and defines technical terms.

g. Geohydrologic Analysis.

The relationship between streams and groundwater can be crucial, particularly in arid regions, to areawide water usage. A detailed water balance investigation is generally conducted to account for water interflow between the two systems. This type of analysis is used to determine the location and extent of aquifers as well as their direction and quantity of flow.

4.1.3 Selection of a Preliminary Corridor

Upon completion of the existing stream studies, the preliminary selection of the stream diversion corridor should be performed. This location process is determined to a large extent by the available topography, existing land uses, economic considerations and regulatory inputs in addition to whatever purpose the diversion is to serve. For siting facilities and roads, the diversion route will most likely remain in the vicinity of the original stream valley. However, streams within a surface mining leasehold may be rerouted in a completely different direction than the original stream, although eventually tying back into the original channel. Stream length and alignment are not necessarily important at this stage since it is a corridor site selection and further refinement is required before the actual route is selected.

After the corridor location has been chosen and mapped, the next step is to walk the corridor, especially if the route selected is through an undisturbed area. During this process a probable channel alignment can be marked out and site characteristics noted. Some conditions that should be examined are:

- Points of significant breaks in grade.
- Location of rock outcrops and soil conditions.
- Location of tributary junctions which will require special consideration during design.
- Location of any parks, roads, fencelines, building and utility crossings which may or may not be on the corridor mapping.
- Location of trees and other features which may be desirable to keep and integrate into the channel route.

Subsurface and geologic information may also be needed to select the proper route. In undisturbed areas, the identification of the geomorphology of deposits in which the channel will be located and identification of the stratigraphic units and their properties (stability, weatherability, durability, chemical composition) can be important in route selection. In disturbed areas the erodibility of the disturbed material and the acid or toxic forming potential need to be examined. Depending on regional geology and the integrity of the original materials, test borings may be required to characterize the subsurface conditions along the proposed route.

4.1.4 Determination of the Design Discharge (Q)

Sizing a channel basically requires that the cross-sectional geometry be determined for a given discharge and a channel slope. For the most part the channel slope is fixed, due to upstream and downstream constraints (although variations in slope are not only unavoidable due to construction limitations and materials within the channel, but also desirable to add diversity to depth of flows). Therefore the controlling factor for determining the geometry is the design discharge.

In designing a channel a decision must be made as to what frequency would be acceptable for flooding or overtopping the streambanks. For natural streams this reportedly occurs in a range of every 1.5 to 2.5 years, with 2.0 years being commonly used to represent natural systems. This means that each year there is a 50 percent chance that a bankfull discharge will occur and this discharge is symbolized as Q_2. A Q_{10} represents a discharge that in any given year has a 10 percent chance of being equalled or exceeded. For rivers and streams the base floodplain is defined as that part of the valley that would be inundated by the Q_{100} or the 1 percent chance flood (Federal Highway Administration, 1979).

Design discharges may also be based on a particular precipitation event, such as the 10-year, 24-hour storm. A 10-year, 24-hour storm refers to the amount of precipitation falling over a 24-hour period that is equalled or exceeded once in ten years. This storm event will cause a certain discharge in the stream. The advantage to this method is that it uses a predetermined rainfall event which is better defined for most geographic areas.

In theory, when designing a channel to replace a natural stream, the logical design discharges to use are the Q_2 for the main channel and Q_{100} for the floodplain configuration. However, due to space limitations and regulatory criteria this may not always be possible or allowed by the regulatory agency. Other considerations include existing structures, dwellings and property that would experience frequent flooding if the streambanks were limited to the Q_2.

Once the design discharge frequency has been established, the magnitude of the event must be derived. There are three basic approaches to estimating design events. First and simplest is to use a regionalized empirical equation developed and available from the U.S. Geological Survey for many areas of the United States. The major criticism of this method is its unreliability for a site-specific situation, particularly since these regression equations do not account for major disturbances such as surface mining, in the watershed of concern.

A second type of technique is a statistical analysis of streamflow gaging data to develop a flood frequency curve. The problem here is that seldom if ever is a gaging station that has been operating for a sufficient length of time located at the site of the diversion. If some gaging data is available either on the stream of interest or from a nearby stream, methods of adapting this information to the relocation reach are available. This information will generally be less reliable than data taken on the actual stream to be diverted.

The third type of technique relates storm or precipitation events in a watershed to discharges. Both the Rational Method and the SCS Method are examples of this type.

Discussions and applications of the aforementioned techniques can be found in standard hydrology textbooks such as "Hydrology for Engineers" (Linsley, et al. 1982) or government documents such as the "National Engineering Handbook, Section 4" (Soil Conservation Service, 1977). A reference specifically addressing the hydrology of disturbed lands has been prepared by Barfield, et al. (1981) and provides an excellent discussion of the methods available for design discharge analysis under various field conditions.

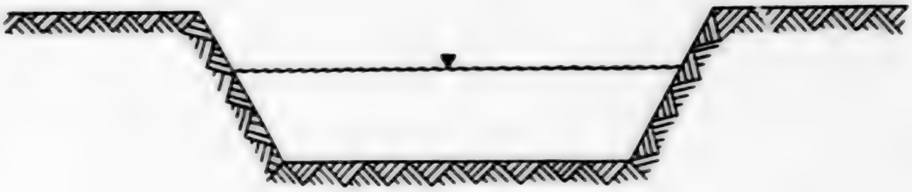
One technique uses the channel geometry of the existing stream to estimate streamflow characteristics at ungaged sites (Osterkamp and Hedman, 1979). The methodology is based on the consideration that the channel size and shape is a direct result of the water and sediment discharged past the site. Various stream widths are taken which correspond to particular discharge-channel configuration events and the composition of both the stream bed and banks. This information is correlated to gaging data at the site to develop equations that can be used in similar ungaged watersheds. However, the authors caution that the method yields the best results when the measurements are taken by hydrologists experienced in channel-geometry techniques.

In situations where the relocated stream will be receiving discharges from the mining operation (e.g., a sewage treatment plant outfall), the flow available to act as a receiving water will be important. However, in contrast to sizing a channel which requires that the probable maximum flows be determined, the hydrologic event of interest is the probable minimum flow. Determination of this event will provide information on "worst case" conditions for water quality because less water will be available to dilute the effluent discharge. In many states the minimum low flow specified for which water quality standards are applicable is the 7-day, 10-year low flow event (Q_{7-10}). This event represents the lowest flow expected over a seven-day period which has the probability of occurring once in ten years. Flows less than the Q_{7-10} are generally exempt from state water quality standards, but this exemption criterion should be verified by the appropriate agency in which the discharge is located.

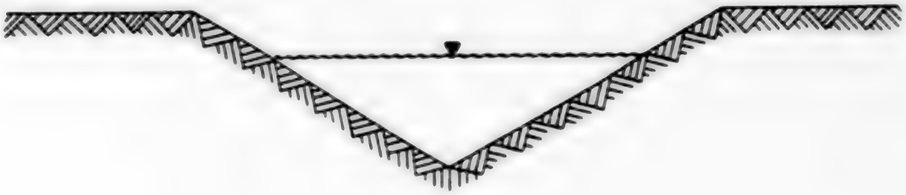
4.1.5 Determining Channel Geometry

The geometry of a channel describes the dimensions of the cross-section of a waterway and defines the cross-sectional area. Typical shapes, shown in Figure 4-1 include trapezoidal, V-shaped and parabolic. In discussing cross-sections of channels, hydraulic engineers often use the terms best hydraulic section and stable hydraulic section. The "best" hydraulic section is one that has the least wetted perimeter for a given area, and thereby being capable of conveying the maximum discharge for that area. A semi-circular channel represents the most hydraulically efficient section under these conditions since it has the least length of perimeter for all shapes that contain an identical area. A stable cross-section for an erodible channel is one in which no erosion will occur at a minimum water area for a given discharge and the shapes that enhance stability are reportedly elliptical or parabolic (Chow, 1959). The problem with using either semi-circular or parabolic profiles as the shape of a channel is in construction since it is difficult to excavate channels that approach these cross-sectional forms. For the design of stable, erodible channels (unlined), two approaches to approximating the necessary cross-section have been developed (Chow, 1959). One method is based on calculating the maximum permissible velocity that will not scour the channel (i.e., will not cause erosion of the channel bottom). The velocities will vary in accordance with the materials lining the channel, Mannings 'n', water depth and sediment content in the water. This method has been revised and refined by the Soil Conservation Service for use in their design of open channels (Soil Conservation Service, 1977).

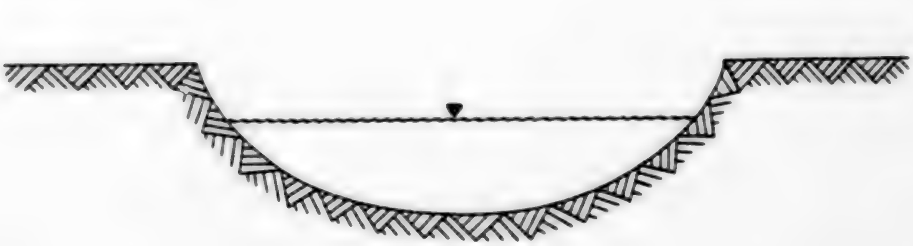
A second procedure applied to the design of channels is the method of tractive forces, which is based on the identification of the force necessary to move particles along the bed and



TRAPEZOIDAL



V-SHAPED



PARABOLIC

Figure 4-1. Common channel shapes.

banks of the channel. The channel is then designed so that these particles are on the verge of moving, but remain in place. The method is summarized as follows from Chow (1959):

> The first step in the design of erodible channels by the method of tractive forces consists in selecting an approximate channel section by experience or from design tables, collecting samples of the material forming the channel bed, and determining the required properties of the samples. With these data, the designer investigates the section by applying the tractive force analysis to ascertain probable stability by reaches and to determine the minimum section that appears stable.

The development of a third common method which utilizes the regime concept is based on the theories of sediment transport, discharges and channel dimensions in a state of dynamic equilibrium (Nunnally and Keller, 1979).

Several shortcomings are associated with each of these methods. Each is based on the assumption that steady uniform flow exists in the channel which is to say that the depth of flow does not change either over time or at any location along the channel. This situation is not encountered in a natural stream. The other major shortcoming is that these methods are applicable to straight reaches and must be modified using the designer's experience and judgment to account for bends and meanders. Even with these simplifying assumptions, the application of these methods is time consuming and tedious, even with the use of design tables such as those contained in Brater and King (1976) "Handbook of Hydraulics" and design charts contained in the U.S. Department of Transportation (1961) "Design Charts for Open-Channel Flow."

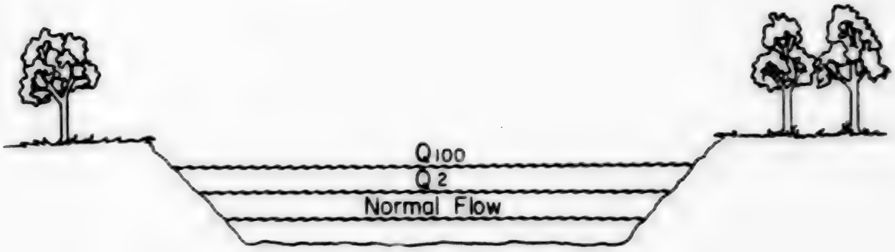
A more direct approach has been suggested for the estimation of channel parameters as part of the design of diversions in surface mined areas (Bhowmik, 1981). This approach utilizes a series of simple equations for channels constructed in sand bed materials and another series of equations for gravel beds. Adjustments to the design must be made for bends in the channel because the methodology is for straight reaches. These modifications include deepening the channel, adjusting bank slopes and increasing bank height at the bends.

The problem with all of the standard approaches to the design of stream channels is that the resulting channel configuration tends to be overly wide with narrow floodplains, primarily due to the selection of a low probability design discharge and the designer's intention for the main stream channel to contain this event. This creates a situation where, during normal to low flows, flow depth is extremely shallow. The stream then receives increased exposure to solar radiation, which increases summer water temperatures and stressful conditions for some fish species. Narrow floodplains do not provide much area for streamside vegetation, resulting in little riparian habitat and minimal shading potential for the stream.

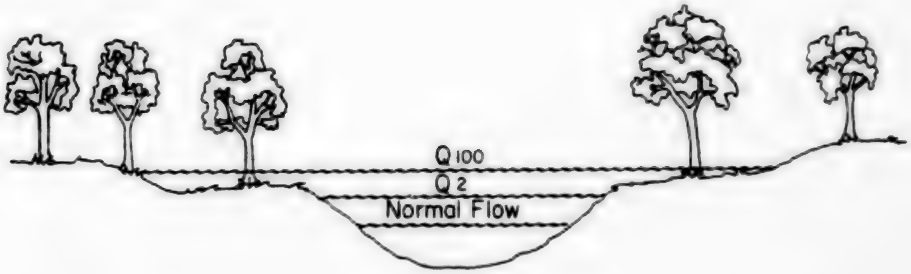
A preferred design incorporates the design discharge for the 50 percent yearly occurrence, (Q_2) for the "main" channel and a broader floodplain which contains the 1 percent discharge (Q_{100}). Figure 4-2 provides cross-section views of these alternatives. This "channel-within-a-channel" concept can be further manipulated so that riparian vegetation plantings are conducted at the elevation of the Q_2 event, thereby encouraging the establishment and maintenance of streamside vegetation by periodic inundation.

4.1.6 Channel Alignment

Channel alignment as discussed in this section, includes both the horizontal locations of the channel path



MAIN CHANNEL SIZED FOR 100-YEAR FLOOD



MAIN CHANNEL SIZED FOR 2-YEAR FLOOD WITH FLOODPLAIN TO CONTAIN 100-YEAR FLOOD

Figure 4-2. Alternative channel cross sections.

(i.e. straight vs. meandering) and the vertical alignment, also referred to as the longitudinal profile or the stream slope or gradient.

a. Horizontal Alignment.

Selection of the channel alignment is affected by both economic and physical constraints. The Soil Conservation Service (1977) lists several major factors that affect the location of a channel alignment. These include economics, topography, size of the proposed channel, the existing channel, tributary junctions, geologic conditions, channel stability, right-of-ways, existing bridges, required stabilization measures, farm boundaries, and land use.

Many of these factors were considered in the selection of the channel corridor (Section 4.1.3). Factors often examined in the existing stream are the total length of stream and the meander pattern. Terms associated with meander patterns include the meander wavelength, meander width and radius of curvature (see Figure 2-2). These parameters can usually be measured from aerial photographs.

In laying out the stream diversion course, the general intent should be to imitate the original stream in length and meander pattern. However, when laying out the stream course several factors that need to be considered include the physical processes which occur in the stream, the type of terrain, the location of the mineable coal and property ownership.

The comparison of the total length of stream for the original versus the diverted stream is important from two aspects. The first is to allow for the fall of the stream over its length which is the stream gradient and then adjust the gradient to keep sufficient velocities in the stream to transport sediment (usually around two feet per second), while not exceeding velocities that will cause erosion in the channel (generally greater than five feet per second). In addition, the stream gradient at the upper and lower boundary of the diversion must closely approximate the natural channel slopes of the upstream and downstream undisturbed sections.

The second consideration is that by reducing the stream length, aquatic habitat will be lost. Loss of habitat not only means that there is less physical space for organisms to occupy, but it may also affect upstream and downstream conditions by competition of displaced animals with those already inhabiting the undisturbed stream reaches. Conversely, by increasing stream length, there is an opportunity to gain additional aquatic habitat.

Temporary diversions on surface mine sites are often characterized by lengthening streams because the stream is routed around the perimeter of the active mining area where it once flowed through the active mining area. Prior to passage of environmental regulations governing these activities, permanent diversions were often designed to be straight channels and usually resulted in a shorter stream length. It should be noted that loss of stream length may not always be an adverse impact; an evaluation of the quality of the stream habitat loss should be made in regard to the replacement habitat value of the new channel.

A unique feature of diversions on surface mine lands is the possibility of routing streams through final cut lakes. In this case, stream habitat is replaced by lake habitat which, in some situations, may be the only viable alternative. This situation was examined at a surface mine in western United States (Vinikour, 1981 and 1980) . The results of the study indicated that a tradeoff occurred whereby the lake blocked upstream migration of some aquatic macroinvertebrates and the composition of species shifted to the type of invertebrates commonly found in lakes. However, the aquatic invertebrates drift process was not interrupted sufficiently to affect downstream populations and the lake served to reduce downstream sediment and nutrient loading from an upstream sewage treatment plant discharge. Thus, stream diversions directed through final cut lakes also have the additional benefits of the pit serving as a sediment and nutrient trap as well as adding habitat diversity. Potential hydrologic advantages include providing additional flood storage and providing a mechanism for maintenance of increased base flow. Therefore, if water quality conditions in the final cut lake are satisfactory (no acid- or toxic-forming materials are exposed to degrade water quality) routing through these impoundments may be an acceptable and attractive alternative.

When designing a diversion to include meanders, the engineering aspects become extremely complex because the stream processes involved in the formation and migration of meanders have not been well defined and thus prediction of what will occur, particularly in highly erodible materials will be speculative (see Figure 4-3). Probably the single most important factor in establishing a stable channel section that includes meanders is the composition of the bank materials. Coarse, gravelly materials will be less likely to wash away and will permit the inclusion of meanders that are more natural in appearance. Banks composed primarily of fines such as silt or clays will tend to erode, enlarging the channel so that during low flow conditions, inadequate water depths will prevail. Under these conditions, two possible alternatives are available. One is to reinforce the bank using armoring such as rock riprap; or secondly, the channel can be laid out with very gentle meanders that allow the natural erosive power of the stream to develop the meanders gradually. This second scenario can be enhanced from a fisheries standpoint through the use of current deflectors as discussed in Chapter 5. A stream alignment based solely on imitating the original stream pattern without regard for the materials in which the channel is to be constructed may be vulnerable to excessive bank erosion which affects not only the relocated section, but also results in downstream sedimentation. It is important to emphasize that the inclusion of gradual meanders in stream design is solely an attempt to initiate formation of a natural stream pattern rather than to provide a channel configuration that will remain unchanged over time. Eventually the stream will form its own meander pattern which may or may not be similar to the original constructed channel design.

b. Vertical Alignment (Longitudinal Profile).

Part of the inventory of the original stream conditions should be an analysis of not only the overall stream gradient in the reach to be affected, but also the variation in gradients within the reach. Incorporating similar variations in the new channel should be considered when practical, to provide a diversity of conditions that is beneficial to aquatic life. The existing stream information should also include a determination of the pool: riffle sequence. Pools are defined as a stream section of deep, slow-moving water which occurs in areas of relatively flat gradients. Riffles consist of faster, shallower water in higher gradient reaches. These areas alternate periodically in a natural stream during normal to low flows, but disappear during high discharge events when the water surface elevation increases. Geomorphologists have observed the pool:riffle spacing and have concluded that on the average the sequence is repeated every five to seven times the width of the channel (Leopold, et al. 1964).

Gradients and the pool:riffle sequences can be manipulated to benefit aquatic resources and provide stability in the stream, based on the composition of the channel bed and banks. A U.S. governmental agency report provides several suggestions that can be considered in reference to modifying stream gradients to benefit stream stability (U.S. EPA, 1973):

- Pool and riffle areas can be developed by varying the bottom width of the channel and channel slope.

- Flat gradients should be used in reaches containing highly erodible soils and conversely, the gradient should be steepened in erosion resistant areas.

Figure 4-3. Channel meanders on a relocated stream on a surface mine in Illinois.

- Gradient manipulations can be used to lessen meander development, promote channel stability, and minimize sediment from channel and bank erosion.

- To vary gradients, use devices such as drop structures, chutes, steepened rock armored sections or cascade structures, thereby allowing the use of more moderate gradients above and below these high gradient sections. However, care should be used when considering these structures because the devices must be selected and installed in such a manner that they do not inhibit fish movement.

The important beneficial aspects of pools and riffles in waterways have been enumerated (Nunnally and Keller, 1979). These include:

- The variety of depths found during low flows in pools and riffles are necessary to aquatic life because they supply areas to feed, breed and provide cover.

- At high flow, these areas can provide shelter from excessive water velocities.

- Pools and riffles maintain a natural sorting process for sediments such that the coarser materials are found in riffles and finer materials settle out in the pools. This provides a diversity of substrate for bottom-dwelling organisms.

- A wider variety of riparian vegetation exists along areas where riffles and pools occur.

A channel with a uniform depth and gradient generally lacks the diversity of habitat necessary to encourage the repopulation of a relocated channel by a variety of aquatic life.

4.1.7 Channel Bed and Bank Linings

When selecting channel bed and bank materials, an evaluation of expected hydrologic and hydraulic conditions, identification of subsurface conditions along the proposed route and the habitat available for aquatic life in the relocated channel must be made. A distinction should be made between linings and bank armoring in that linings are continuous along both the bed and banks up to the high water mark. Bank armoring, which includes riprap, is used to denote treatment of selected areas to protect against or retard erosion.

Channels may be lined or unlined. Lined channels, which include vegetative as well as flexible and rigid types, serve several purposes. The primary use of rigid liners is to reduce frictional losses thereby increasing velocities and conveying larger volumes for a given cross-sectional area in a more efficient manner without eroding the channel. Vegetative and flexible liners in erodible channels can be used to increase the roughness of the channel, which reduces velocities and scouring. Lining a channel with gravel or cobble increases roughness, while at the same time provides substrate for aquatic organisms and a more aesthetically pleasing watercourse.

Unlined channels used in water resources projects in the past were primarily confined to those excavated in bedrock. More recently, the emphasis has shifted to creating more naturally-appearing channels. Because of this, greater attention has to be focused on limiting velocities and/or frictional forces in determining channel slopes and cross-sectional areas to reduce the potential for erosion.

Vegetative linings are appropriate for small, ephemeral streams and ditches at a mine site where velocities are not excessive. Grass-lined diversion channels are generally found to be the most economical channel liner (Tourbier and Westmacott, 1980). Table 4-1 provides a range of permissible velocities in streams vegetated with grasses, based on slopes and soil types. As indicated in the table, grass-lined channels function best in areas where slopes are less than 10

Table 4-1. Permissible velocities for channels lined with vegetation (Adapted from Tourbier and Westmacott, 1980).

		Permissible Velocity[a]	
	Slope Range[b] (percent)	Erosion Resistant Soils (fps)	Easily Eroded Soils (fps)
Bermuda grass	0-5 5-10 Over 10	8 7 6	6 5 4
Bahia Buffalo grass Kentucky bluegrass Smooth brome Blue grama Tall fescue	0-5 5-10 Over 10	7 6 5	5 4 3
Grass mixtures Reed canarygrass	0-5[b] 5-10	5 4	4 3
Lespedeza sericea Weeping lovegrass Yellow bluestem Redtop Alfalfa Red fescue	0-5[c]	3.5	2.5
Common lespedeza[d] Sudangrass[d]	0-5[e]	3.5	2.5

[a] Use velocities exceeding 5 fps only where good covers and proper maintenance can be obtained.

[b] Do not use on slopes steeper than 10% except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

[c] Do not use on slopes steeper than 5% except for vegetated side slopes in combination with a stone, concrete or highly resistant vegetative center section.

[d] Annuals -- use on mild slopes or as temporary protection until permanent covers are established.

[e] Use on slopes steeper than 5% is not recommended.

percent and velocities are less than 6 feet per second. Vegetative liners do not function properly if inundated for long periods of time because the plants cannot survive under these conditions. A detailed discussion of the function of vegetative liners in a channel has been provided by Kouwen and Li (1980). The procedures to follow in the design of vegetated waterways has been described by Barfield, et al. (1981).

Flexible liners include artificial materials such as plastics and fiberglass; natural woven materials like jute or excelsior; and rock, gravel or clay. Jute, excelsior and fiberglass liners are normally used for temporary erosion control on vegetated diversions. Plastics and clay liners may be used in situations where an impermeable seal is desired to reduce infiltration through the stream bed. An example of this is in reclamation of abandoned mined land areas where stream infiltration into inactive underground mines contributes to the formation of acid mine drainage. Clay liners have been used in Pennsylvania to limit acid mine drainage formation (Miorin, et al. 1979).

Probably the most aesthetically pleasing and ecologically sound use of flexible liners is of the rock or gravel type. The type of substrate available to aquatic organisms, particularly benthic macroinvertebrates is a major governing factor in determining the structure and dynamics of the stream community (Reice, 1981). Much of the stream life depends on substrate for shelter, cover, and surface of attachment, and many of the adverse biological effects attributed to stream alterations stems from loss of suitable or stable substrate (Matter, et al. 1981; Congdon, 1971; Arner, et al. 1976; Griswold et al. 1978; Huish and Pardue, 1978). As mentioned in Chapter 2, streams exhibit a self-armoring tendency where the finer materials are washed downstream, leaving the heavier, coarser gravel, cobble and boulders (Figure 4-4). Use of these materials to line the stream hastens this process and provides a less erodible surface. The Tongue River relocation project, as part of a surface mining operation in Wyoming, successfully utilized this type of liner in creating a stable channel and the subsequent recolonization of the stream by aquatic invertebrates (Gore and Johnson, 1979 and 1980).

There are, however, some potential drawbacks to lining the entire stream with rock or gravel. The cost involved with such an undertaking may be prohibitive and the biological benefits may not be achieved if the substrate is blanketed by sediment deposits (Shields, 1981). Another key consideration is whether or not the rock and/or gravel will remain where placed or be washed away during periods of high flow. A rule-of-thumb approach is to examine the sediment size gradation in pools and riffles upstream and downstream from the affected reach and attempt to match this size range when considering rock linings. Proper installation of stone liners requires that a gradation of sizes be placed, beginning with fine gravel bedding, overlain by the larger rock. This inhibits the larger stones from burying themselves in the channel bottom.

Rigid liners made from Portland cement, asphalt cement and shotcrete have definite hydraulic advantages due to their low roughness and resistance to erosion. However since they are rigid they are susceptible to developing cracks and are not natural in appearance. Rigid linings do not provide a good substrate for aquatic organisms and should be reserved for situations of very steep gradients in ephemeral streams or conveying overland flows in diversion ditches that have a very limited potential for supporting aquatic life. One beneficial application of concrete channels is in providing a bypass around obstructions to allow fish to move upstream or downstream. These fishways, discussed in Chapter 5, contain baffles to reduce velocities and permit the passage of fish through dams or culverts or even steep, natural stream sections. The use of paved or rigid linings and measures to enhance them for fish including providing shade to lessen the heating effects of lined channels,

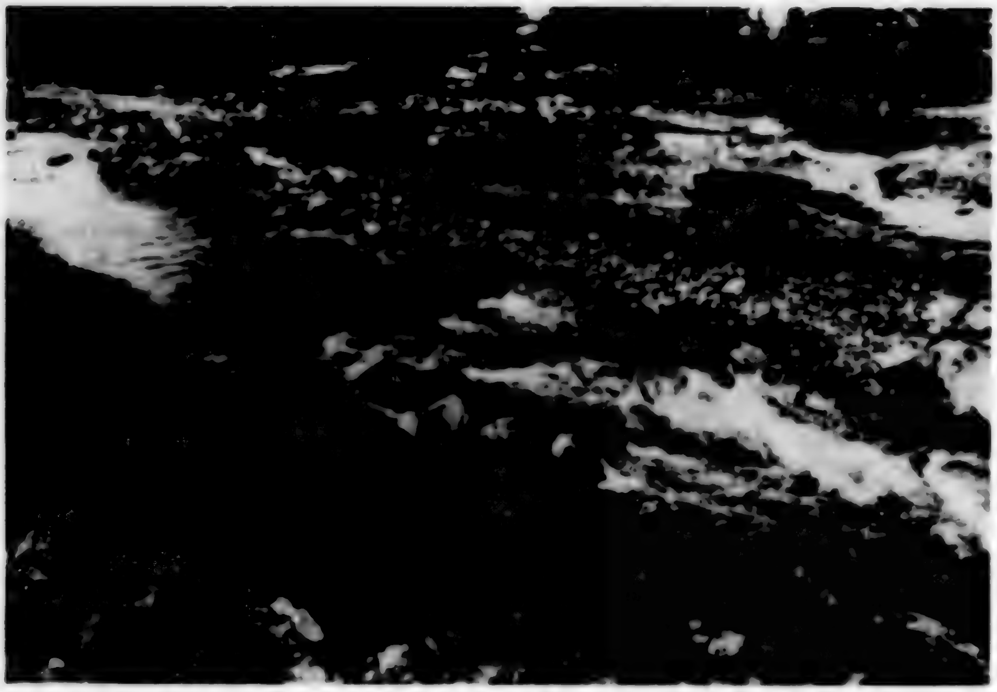


Figure 4-4. An example of natural armoring along a stream in Colorado.

placing boulders in the concrete, providing low flow channels, resting areas and spawning channels and anchoring boulders or stumps along the channel to provide cover and shelter has been addressed by Shields (1981).

4.1.8 Streambank Stabilization

Streambanks on a meandering stream are constantly subject to erosion on the outside of bends and deposition on the inside of bends. In addition, streambanks on newly constructed channels are vulnerable to erosion from both stream action and surface sheet flow. To protect the banks, consideration must be given to the angle of the bank slopes, controlling erosion from overland flows entering the stream, establishing bank vegetation, and in areas exposed to potentially damaging streamflows, providing bank armor.

a. Channel Side Slopes.

Selecting the side slopes of a channel requires the consideration of the bank material, the limitations of the excavating and channel maintenance equipment, the required dimensions to convey the design flow, and the stream processes. Channel side slopes of 3H:1V or flatter have been recommended to facilitate channel maintenance (Tourbier and Westmacott, 1980). The following side slopes have been recommended for channels built in various kinds of materials, although they should be checked by methods previously mentioned in Section 4.1.5 for permissible velocities and tractive forces (Chow, 1959).

Material	Side Slope
Rock	Nearly vertical
Muck and peat soils	0.25H:1V
Stiff clay or earth with concrete lining	0.5:1 to 1:1
Earth with stone lining or earth for large channels	1:1
Firm clay or earth for small ditches	1.5:1
Loose sandy earth	2:1
Sandy loam or porous clay	3:1

The stability of the side slopes should be checked by a person qualified to conduct geotechnical engineering investigations, particularly if seepage is expected (Figure 4-5). Also, to account for natural stream forces and to give the channel a more aesthetic appearance, the bank slopes should be steepened on the outside of bends and flattened on the inside.

b. Control of Overland Flows.

Plans to control overland flow so that the banks do not suffer from rill and gully erosion (see Figure 4-6) should be incorporated into the design. Construction of small diversion ditches along the tops of the banks with periodic rock-lined chutes or downdrains to direct surface runoff down the slopes will help minimize bank erosion. These structures should be provided at designated locations, selected on the basis of topography. Due to the concentrated flows and steep gradients that these downdrains are exposed to, special attention must be made to ensure their stability and prevent undercutting. Figures 4-7 and 4-8 provide examples of rock chutes used in stream channel relocation projects on Illinois surface mines. These chutes were located at low points along the channel banks and were lined with synthetic fabrics which are nonbiodegradable and resistant to ultraviolet radiation. Large rock riprap was then placed in the chute and extended into the channel to act as an energy dissipator. Grouted riprap has also been employed on rock chutes to provide a stable, nonerodible downdrain.

c. Streambank Vegetation.

Rapid establishment of streambank vegetation is a key factor in reducing erosion and stabilizing streambanks (see Figure 4-9). This process should be initiated as soon as practical after the new channel has been excavated and vegetation should be allowed to become well established prior to release of water in the new channel. This is particularly true if vegetation is the only protection afforded the stream banks. Depending on the geographic

Figure 4-5. Bank slumping caused by groundwater seeps along a stream in Illinois.

Figure 4-6. Streambank gully erosion due to uncontrolled surface runoff along a relocated stream in Illinois.

Figure 4-7. Rock chute used to control surface runoff on streambank on a surface mine in Illinois.

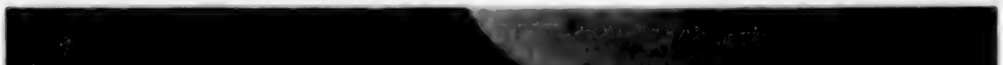


Figure 4-8. Rock chute constructed on a relocated Illinois stream that extends into channel to prevent streambank erosion.

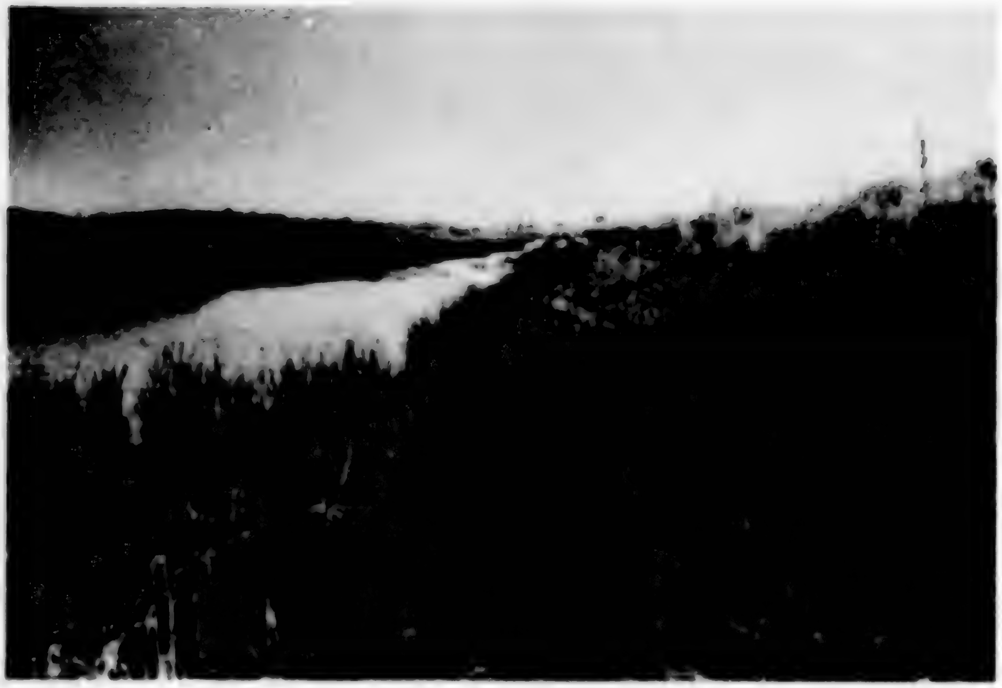


Figure 4-9. Well established streambank vegetation on a relocated stream in Illinois, creating a stable channel configuration.

area, soil conditions and precipitation amounts, it will probably take at least one full growing season and possibly more before the vegetation is capable of withstanding the drag of streamflows. This section addresses streambank vegetation in a generic sense because seeding mixtures or planting procedures will vary according to the geographic area. For specific guidance on this subject, contact should be made with the local Soil Conservation Service office or representative of the state agency (or agencies) involved with stream habitat and/or erosion and sediment control planning. Vegetation guides prepared by the U.S. Forest Service should also be consulted for additional information (Vogel, 1981; U.S. Forest Service, 1979).

1) Plant Species Selection - Two purposes should be served by plant species selected to vegetate streambanks. The initial purpose is to quickly establish cover on the exposed material to minimize erosion. These rapid growth species need to be water tolerant and be capable of developing root systems that will securely anchor the plants into the bank so that in the event that they are subjected to periodic flood discharges they will provide stability of the banks. In the long term, the vegetative species selected should benefit both fish and wildlife by providing food, cover, shelter and shading, and promote bank stability by developing extensive root systems to bind the soil. Some general guidelines for plant selection are:

- Select a variety of grasses, shrubs and trees tolerant of high groundwater levels and of periodic inundation.
- Select species adapted to the region and readily available in the area.
- Select species that are adapted to the soil conditions and slope of the bank (pH, texture, fertility).
- Select species that are compatible with each other and have good growth and survival rates.

The Soil Conservation Service provides seeding mixtures for critical area plantings by region. In addition, individual states have agronomy guides which usually address streamside vegetation.

2) Bank Preparation - Preparing the banks for planting involves developing the seedbed to promote germination, loosening compacted soils and roughening the surface to retain seeds, thereby promoting water infiltration and increasing root penetration. Seedbed preparation efforts are complicated on streambanks due to the steep slopes, which limit the techniques available for mechanical preparation. The method commonly used in streambank work is tracking in with a dozer - running the dozer up and down the bank. The advantages of this method are that the dozers are generally available because they were used to assist in excavating the channel and the compaction caused by tracking in adds stability to the bank.

Preparation efforts may also require that the banks be limed and fertilized, particularly for diversions placed in spoil material. The addition of lime and/or fertilizer should be based on the analysis of representative samples of the material which will cover the banks.

3) Seeding and Planting Techniques - The two general types of seeding techniques are drilling and broadcasting. Seed drills are usually not appropriate for the steep slopes encountered on streambanks. Broadcasters, either hand-held or mounted on vehicles can be used on steep slopes, as can hydroseeders, which broadcast a slurry that contains seed, lime, fertilizer, mulch and water.

Tree and shrub plantings of seedlings requires care and attention to the handling and storage of the plants to reduce mortality and a conscientious planting crew for achieving a high success rate. Planting techniques include mechanized planters, dibble bars and manual digging with a mattock.

Grasses and shrubs should be planted on the upper portions of the bank and beyond the bank for a distance of 25 to 50 feet. Trees should not be planted directly on the edge of the banks because of the limited space available for their root system. Hardwoods planted back from the bank will eventually provide shading for the stream. It has been recommended that gaps of approximately 20 m (66 feet) in every 70 m (230 feet) be left in tree plantings along the south bank, so that the stream is not totally shaded (Dawson, 1978).

4) Mulching - After an area has been seeded it should be mulched to reduce erosion, trap moisture and contribute organic matter (see Figure 4-10). A list of recommended mulches and application rates is presented as Table 4-2. Case studies of three Mississippi streams showed that after one year, the most effective mulch was excelsior erosion control blankets and chopped grain straw anchored with emulsified asphalt. The least effective mulch was paper matting (Bowie, 1981).

5) Maintenance - The banks, once seeded and/or planted with seedlings, should be regularly checked for plant survival and areas that may have been missed during the application of the vegetation. Bare areas should reseeded to limit erosion of the banks.

d. Bank Armoring.

Protection of erodible channel banks, particularly where they are subjected to excessive scouring, may require armoring such as riprap, tire mattresses, asphalt or concrete mattresses, erosion matting, or gabions. These streambank erosion control measures have been the focus of a study by the Army Corps of Engineers (Keown, et al. 1977; Little and Murphey, 1981; Keown and Dardeau, 1980). Retaining structures such as binwalls, curb walls or wire walls may be necessary where space limitation dictates streambanks steeper than can be supported by the material composition of the banks.

Riprap is the most commonly applied bank armoring because it is inexpensive, flexible, durable, easily installed and repaired, capable of providing roughness to the channel to reduce velocities and it is easily modified to appear natural if topsoiled and seeded. Riprap should not be used indiscriminately as completely riprapped banks appear artificial. Instead, efforts should be concentrated on using them in locations where scour is expected (see Figure 4-11). This generally occurs on the outside of bends, extending downstream beyond where the channel begins to straighten, and on the inside upstream bank at the point where the bend begins. It has been suggested that riprap be placed beginning at the 10-year flood elevation (or even higher) and extending down the bank and onto the stream bed for a short distance (Nunnally and Keller, 1979). By placing rock on the bed, the toe is protected and subsequent scouring during high discharge periods will bury the stone. Another method, illustrated in Figure 4-12 is the trench-fill technique, which is a more costly method because it requires excavation and bank grading.

The thickness of a riprap blanket will depend on the degree of the bank slope, stream velocity, and the size, shape and specific gravity of the rock to be used (Hansen, 1968). Minimum sizing procedures for riprap have been developed by the Army Corps of Engineers (Maynard, 1978). Other methods are presented in Barfield, et al. (1981), and design charts for sizing riprap are available from many state highway departments. Figure 4-13 is a design chart developed by the State of California for determining minimum rock weights (California Highway Division, 1960).

Proper installation of riprap requires that the bank be properly graded, a filter of either crushed rock, gravel or sand, or filter fabric be used to line the bank, and then the riprap blanket placed on top. The filter is necessary to keep the bank material from washing through the rock, while still allowing natural seepage from the bank material to

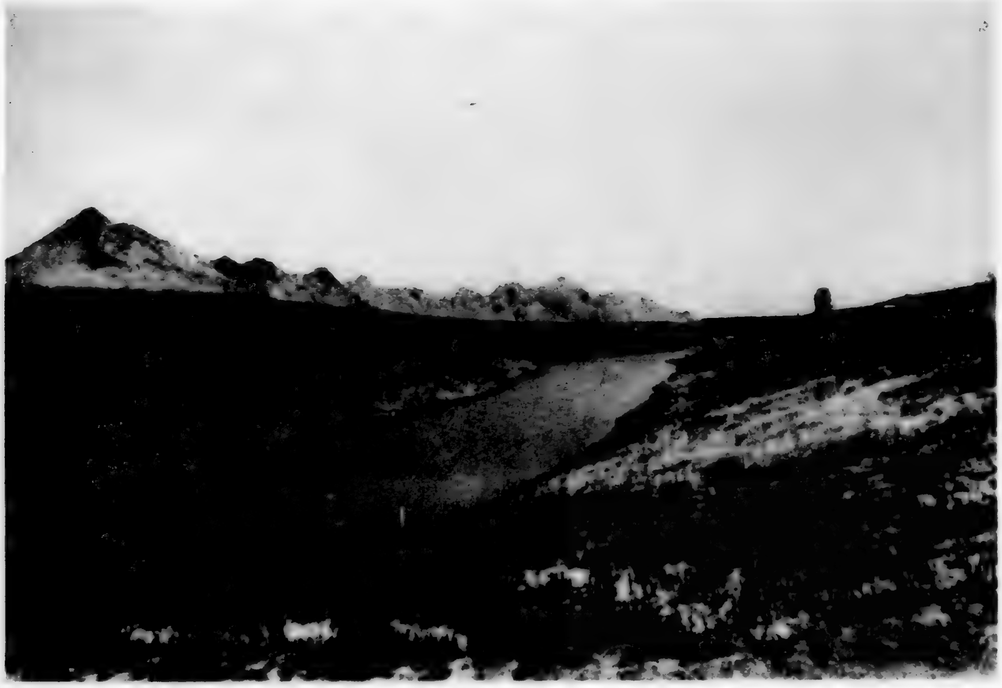


Figure 4-10. Recently seeded and mulched channel for a coal mine stream relocation project in Illinois.

Table 4-2. Application rates for various mulches (Adapted from Ohlssor, et al., 1982).

Mulch Type	Recommended Application Rate (per acre)	Comments
Cellulose Fiber	1,500 to 2,000 lbs.	- waste material from pulp mills - used in hydroseeders - generally dyed green to aid visual metering
Straw	1.5 to 2.5 tons	- unchopped straw is best but requires manual application - generally blown onto surface with power mulcher - should be tacked down with asphalt emulsion or other chemical binders, or pressed into the soil with crimpers or disks - often serves as a source of volunteer vegetation seeds
Hay	1.5 to 2.5 tons	- apply same as straw mulch - can be cut from previously reclaimed areas
Chemical Binders	As specified by manufacturer	- improve the stability of other mulches - generally not adequate if applied alone
Sawdust	1.5 to 2.5 tons	- mixed success - use limited by availability - may require additional nitrogen applications
Wood Chips	45 cubic yards	- apply by power spreader or mulcher - wood chips are bulky and present some handling and spreading problems - may require additional nitrogen applications
Leaves	2 to 3 tons or 100 bales	- disking is necessary - limited to fairly level areas (30 percent) - baling eases handling problems - spread with manure spreader or power mulcher - must be collected and stored each fall
Other Organic Products (e.g., composted garbage, sewage sludge)	10 tons	- light disking required - local source needed to be practicable heavy metals content should be considered
In Situ (e.g., winter wheat, rye, oats, sudan grass, annual ryegrass, field brome grass)	Recommended Planting Rates	- uses quick growing cereal grains and annuals to provide erosion control - resulting crop residues provide a satisfactory mulch for desired plant mixtures broadcast seeded the following year.

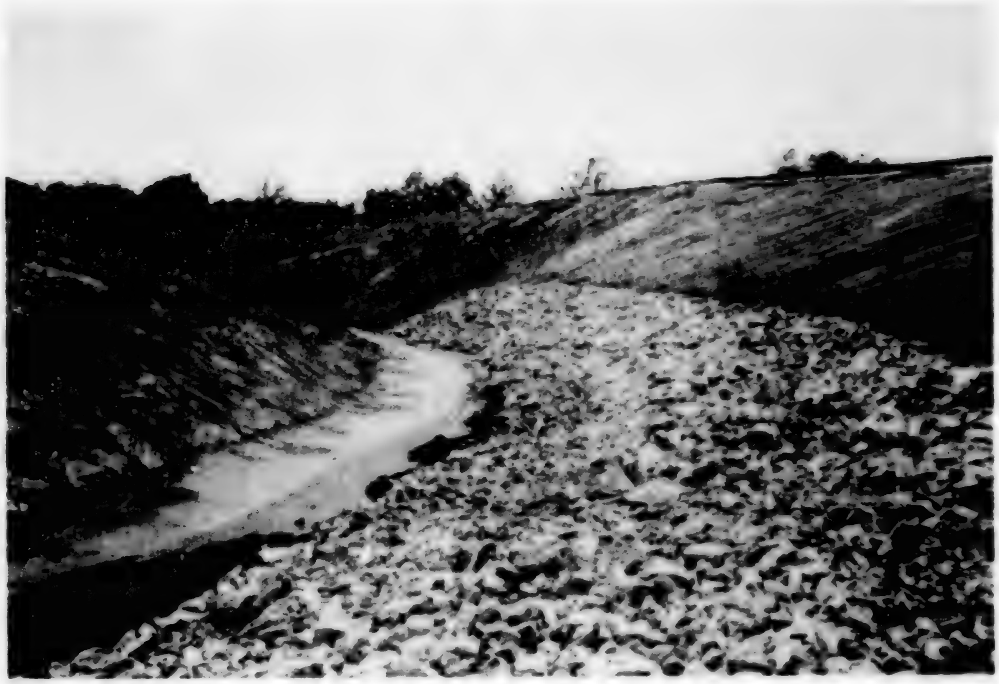


Figure 4-11. Newly excavated stream diversion channel with riprap bank protection in Illinois.

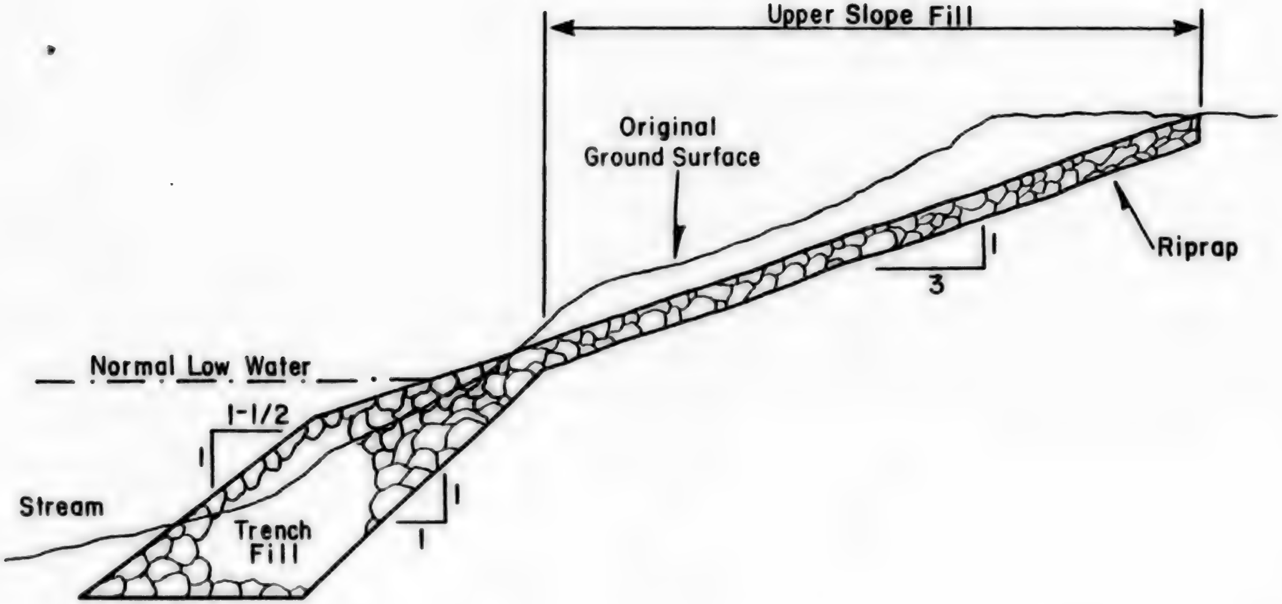


Figure 4-12. Trench-fill revetment (Adapted from Keown, et al., 1977).

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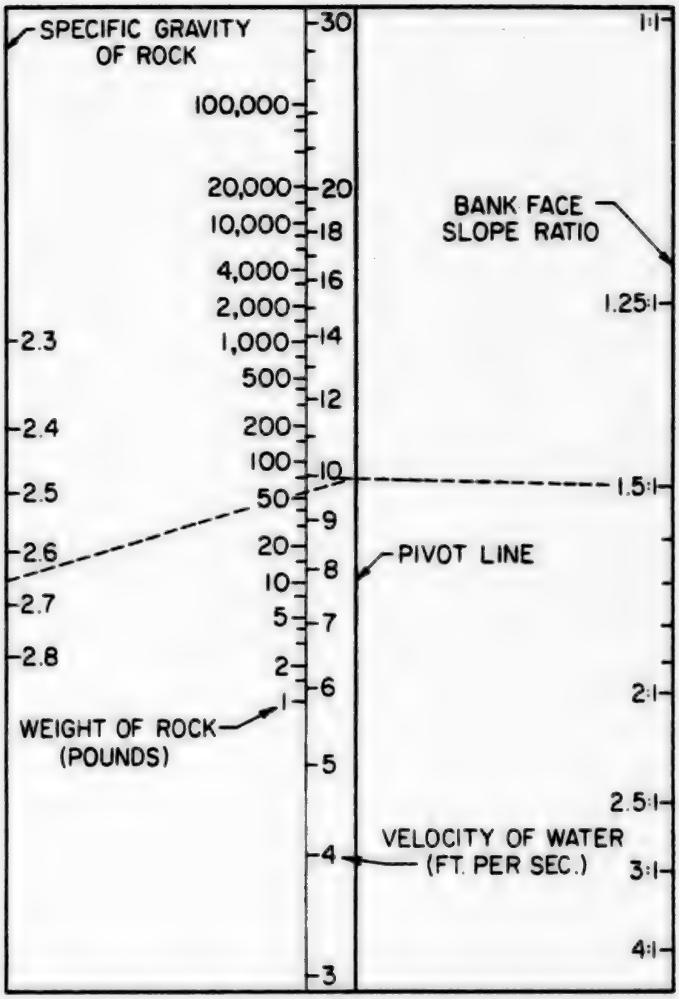


Example: Find bank slope ratio (1.5:1) on righthand scale. Extend line to appropriate water velocity (10 feet per second) on right side of center scale. Find specific gravity of rock (2.65) on lefthand scale. Extend line to intersect first line at "Pivot line." Read weight of rock (57 pounds) where second line crosses scale.

Figure 4-13. Alignment chart for determining weight of stone to be used as riprap (California Highway Division, 1960, Adapted from Hansen, 1968).

occur. An analysis of filters for rock riprap can be found in Keown and Dardeau (1980).

Where rock suitable for riprap is not available locally or prohibitively expensive, other structures such as gabions or tire mats may be appropriate. Alternative devices generally share one thing in common in that they are not natural in their appearance. However, establishment of vegetation on bank stabilization structures will help alleviate this situation.

Retaining structures (Figure 4-14) may be necessary where mine surface facilities are constructed in a stream valley. Under these conditions, structures not susceptible to undercutting, such as binwalls, crib walls, or wire mats are used to protect the surface facilities from flooding.

4.1.9 Channel Transition Zones

The improper design of a relocated channel section has the potential to affect not only the immediate reach of concern, but also upstream and downstream on the main channel as well as any tributaries entering these sections. The primary considerations are matching existing gradients on the initial upstream section and downstream terminus of the project with the new channel section. Increasing the gradient will cause upstream degradation of the channel bed and a corresponding aggradation of the downstream channel. The potential for bed degradation can be estimated by plotting the natural grade downstream of the project and extending the grade line upstream through the modified reach (Shields, 1981). The difference between the extended profile and the design profile is an indication of the potential for degradation.

Another related problem is that the newly constructed channel section is normally hydraulically more efficient than the adjoining downstream natural section, that is, the new channel will convey high discharges more efficiently. The resulting effect is that the downstream section will now be more susceptible to flooding and sedimentation.

Tributary junctions are another potential problem that can often be overlooked when channel relocations are designed. Figure 4-15 illustrates the tributary channel degradation and main channel bank erosion which occurred because of the lack of side channel protection measures. This situation resulted because the elevation of the main channel bed was considerably lower than the tributary bed. The tributary cut a deeper channel in a series of small drops or knick points that extended up the tributary channel as the stream attempted to dampen the effect of an increased gradient. Several types of structures such as pipe drops, lined chutes, drop spillways or sediment basins and debris traps have been applied to address tributary junctions (U.S. EPA, 1973). Side inlet devices should empty into areas recessed in the banks of the main channel to minimize damage from floodwaters, ice, or debris and also limit the retardance of flow in the main channel (Soil Conservation Service, 1977). From a biological viewpoint, one of the major concerns with the use of such techniques is that it may block the upstream migration of aquatic organisms or interfere with fish spawning. If the elevation between the tributary and main channel beds is similar, a rock-lined chute (riprap chute) may serve the purpose. Such a chute is natural in appearance and economical if durable rock is available. In addition, if the rock is of sufficient size and weight to withstand flood discharge, it is relatively permanent (see Figure 4-16). For a more substantial elevation differential, a series of small drop structures resembling steps may be required and is preferred to a single, larger drop structure. Low head drop devices that have been utilized to improve fish habitat, such as the jack dam and notched log dam, are presented in Chapter 5. Other considerations include stabilizing and armoring the main channel bank where the tributary enters. Riprapping the main channel across from where the tributary enters to serve as a velocity

Figure 4-14. Wire wall retaining structure along a relocated stream at an underground mine in Utah.

Figure 4-15. Side channel (tributary) erosion caused by a stream relocation project.

Figure 4-16. Stable side channel entrance to a relocated stream in Utah utilizing rock-lined chute technique.

or energy dissipator has also been suggested (Virginia State Water Board, 1979).

4.1.10 Alternative Channel Designs

As stated previously, one of the major criticisms of stream relocations projects is creating wide shallow channels that are not conducive to propagation of aquatic life nor aesthetically pleasing. In cases where a large channel capacity is required for flood control there are alternatives for improving the ecological and visual attractiveness of the project. Two such techniques include the construction of a channel within the main channel for handling normal to low flows and secondly, to provide a separate flood flow channel.

Low flow channels can be excavated within the main channel or by allowing the stream to develop a subchannel through the use of current deflectors (discussed in Chapter 5). Three major considerations for low flow channels include 1) stability of the channel; 2) aquatic habitat within the low flow channel; and 3) overall project aesthetics (Shields, 1981). All three concerns can usually be satisfied by imitating the original unaltered stream channel.

Flood flow channels are designed to be dry under most conditions, conveying flows only during infrequent flooding events. This permits the design of a smaller main channel to carry the more typical discharges. An example of this type of design, prepared by the Soil Conservation Service, is shown in Figure 4-17 (Soil Conservation Service, 1977). Figure 4-18 is a photograph of a flood flow channel in use at a coal mine in Wyoming.

4.1.11 Controlling Stream Access

Newly relocated streams are particularly vulnerable to damage by livestock trampling vegetation and damaging the banks. To discourage this situation, livestock should be limited to specific stream sections by installing fencing along the stream except where crossing or watering areas are necessary. These fences should be set back from the edge of the stream to permit development of riparian vegetation and allow access for fishermen.

Stream fencing should not interrupt animal migration or travel routes. To prevent the interruption of wildlife movements, several recommended practices have been presented (U.S. Forest Service, 1969):

a. For antelope rangelands (see Figure 4-19) -

   - Construct net wire fences to a maximum height of 32 inches
   - Construct barbed wire fences so the bottom wire is at least 16 inches above the ground.

b. Where deer, elk or moose are a concern -

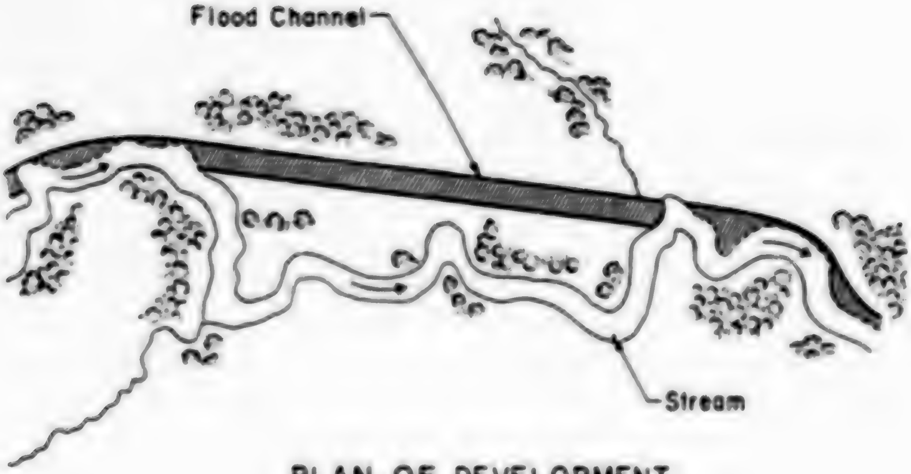
   - Construct fences not more than 40 inches in height
   - Where possible, use poles in place of the top wire to reduce game losses and damage to range fences.

To minimize damage to the stream at the access area, crossing ramps and hanging flood gates should be installed as shown on Figure 4-20 (Pennsylvania Fish Commission, 1980).

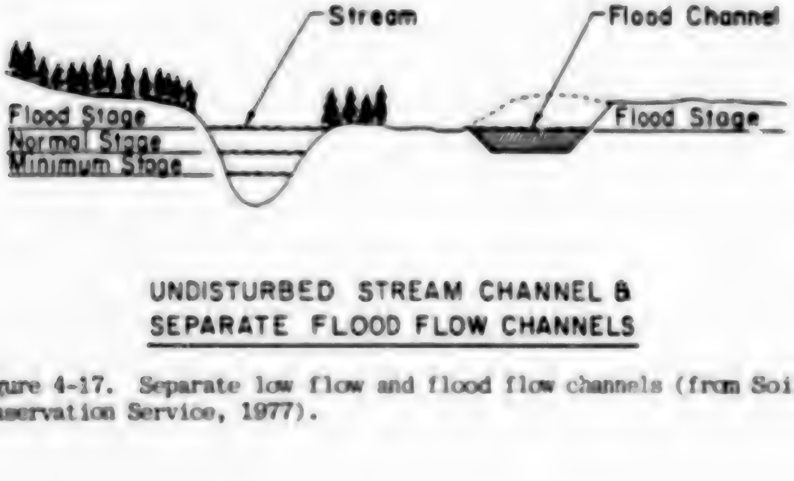
4.1.12 Construction Practices During Stream Channel Relocation Projects

The following provides some general guidelines to assist the mine operator when performing a stream relocation project.

a. When excavating the new channel, begin at the downstream end and work upstream. This will keep the site drainage behind the active construction area. Leave plugs in both the upper and lower ends until the channel banks have been revegetated and are stabilized.



PLAN OF DEVELOPMENT



UNDISTURBED STREAM CHANNEL & SEPARATE FLOOD FLOW CHANNELS

Figure 4-17. Separate low flow and flood flow channels (from Soil Conservation Service, 1977).

Figure 4-18. Separate flood flow channel section at the upstream end of a temporary stream relocation project in Wyoming.

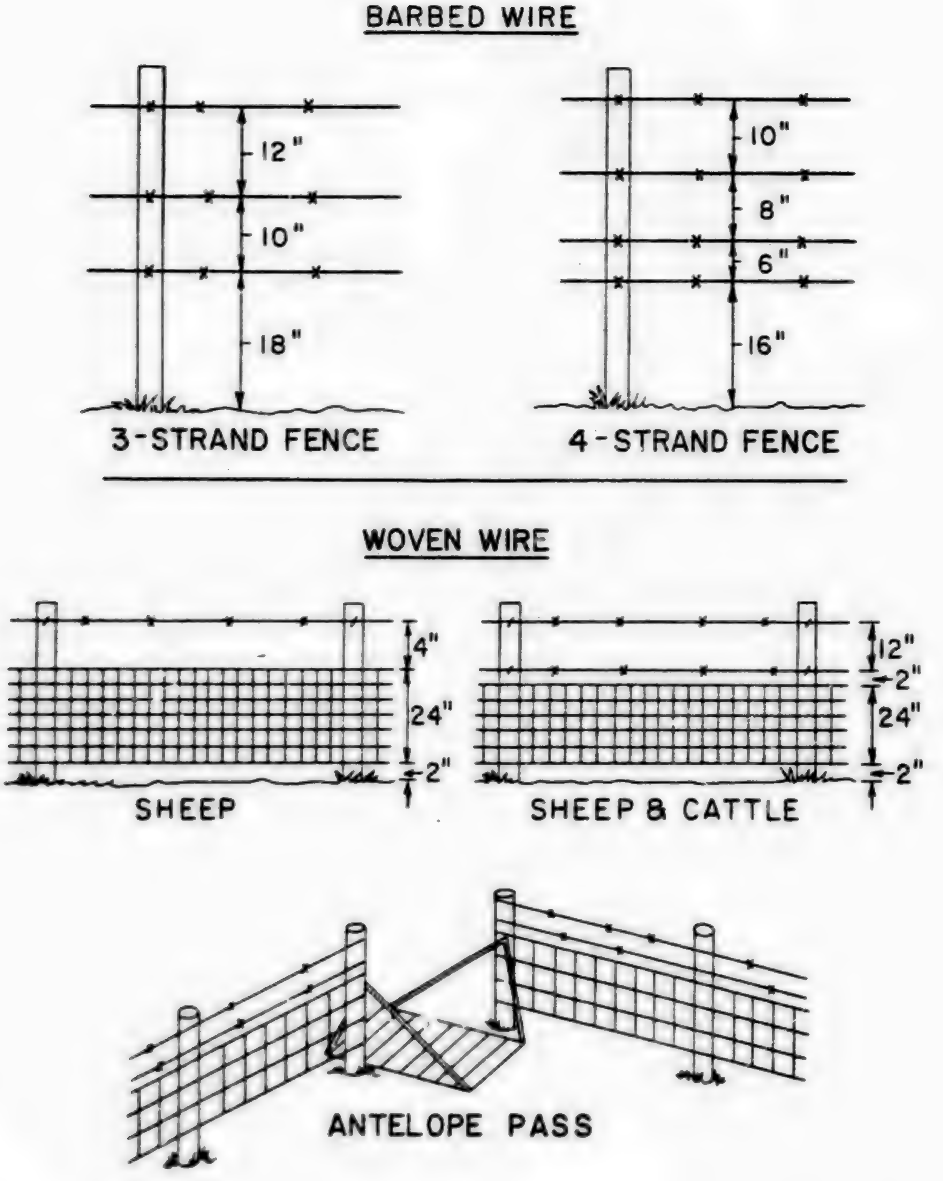


Figure 4-19. Antelope fences (Adapted from U.S. Forest Service, 1969).

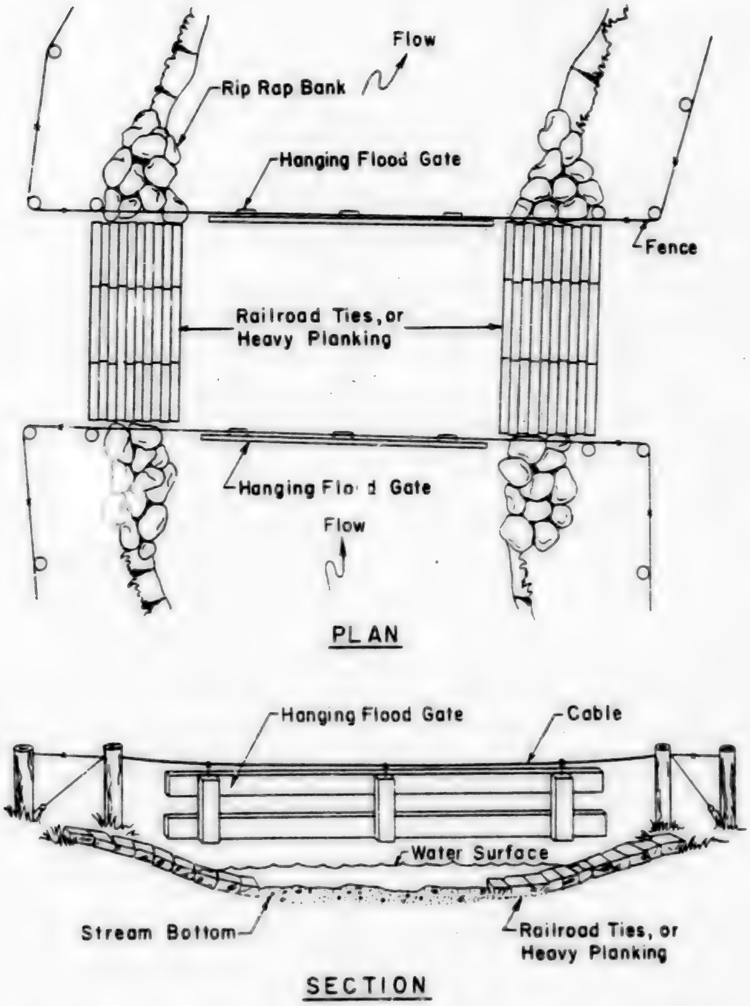


Figure 4-20. Crossing ramp and hanging gate (Adapted from Pennsylvania Fish Commission, 1980).

b. Minimize the disturbed area, particularly if the channel is to be constructed in undisturbed lands. Figure 4-21 shows a stream relocation where the equipment operators remained in the excavated channel, leaving adjacent trees and other vegetation in place. Not only does the stream immediately attain a natural appearance, but it also saves the operator the expense of establishing woody vegetation once the project has been completed.

c. Inclusion of fish habitat improvement structures (Chapter 5) should take place while the channel is dry.

d. Staking out the relocation (in undisturbed areas) should be a flexible process that utilizes natural conditions to vary gradient sideslopes, width and alignment (Federal Highway Administration, 1979). This is also the case when selecting locations for fish habitat improvement devices.

e. Rapid establishment of vegetation and proper installation of drainage control structures are the keys to bank stabilization. These two factors are probably the most important aspects of a successful channel relocation project.

4.2 CHANNELIZATION ALTERNATIVES

Channelization of streams, especially to promote flood control is not commonly associated with coal mining projects. Occasionally streams are "redefined" or enlarged to accommodate larger flows to protect shaft sites or haul roads. Past channelization projects have consisted mainly of straightening and widening streams. This has resulted in overly-wide, straight, steep channels and the removal of most or all of the natural meandering, riffles and pools, and streambank vegetation. Recent approaches to increasing channel capacity without totally eliminating the natural features of a stream have been proposed and implemented. Although not applied specifically to coal mining, this technique, termed the stream renovation or restoration concept, should be applicable to mines where the need is to increase the capacity of a stream, without relocating it.

There are basic design, construction and maintenance procedures associated with the stream restoration approach (Nunnally and Keller, 1979). The approach is to work with the existing stream channel, removing obstructions such as fallen trees and debris to increase the effective cross-sectional area (selective clearing and snagging) and reshaping and/or armoring streambanks to promote stability. The use of heavy equipment is confined to within the channel whenever possible to avoid removal of riparian vegetation. Trees along the edge of the bank are left unless they are severely undercut and are in danger of falling into the stream. Root systems of trees that must be cut down are left to increase bank stability. A case study on streams in North Carolina has been presented by Nunnally and Keller (1979).

A similar technique has been successfully applied to the Wolf River in Tennessee (McConnell, et al. 1980). Table 4-3 presents the guidelines developed by an interagency group and private organizations for this project. Channelization alternatives include (Shields, 1981):

a. Conventional clearing and snagging - removal of all obstructions from a channel and all significant vegetation from a specified width along both sides of the streambank.

b. Selective clearing and snagging - the stream renovation approach.

c. Single-bank modification - enlarging the channel from one side only.

The best alternative depends on site-specific conditions. The shortcomings of the stream renovation/selective clearing and snagging approach are that periodic maintenance is required to keep the channel from becoming constricted and that it does not substantially increase the channel's capacity to convey flood flows. This is balanced by the substantial environ-

Figure 4-21. Relocated streambed excavated in an undisturbed area without removing bank vegetation.

Table 4-3. Clearing and snagging guidelines for Wolf River System (Adapted from McConnell, et al., 1980).

I. General Guidelines

No stream work, including bank clearing and excavation or removal of materials, should be allowed except at specific locations where significant blockages occur. Channel excavation and snag removal should be accomplished with the minimum clearing possible to provide access to the stream.

II. Materials to be Removed from the Channel

A. Log jams. Only those log accumulations that are obstructing flows to a degree that results in significant ponding or sediment deposition should be removed.

B. Other logs.

1. Affixed logs. Isolated or single logs will not be disturbed if they are embedded, jammed, rooted or waterlogged in the channel or the floodplain, are not subject to displacement by current, and are not presently blocking flows. Generally, embedded logs that are parallel to the channel are not considered to cause blockage problems and will not be removed. Affixed logs that are crossways to the flow of waters in the channel and are trapping debris to the extent that could result in significant flooding or sedimentation may be removed.
2. Free logs. All logs that are not rooted, embedded, jammed or sufficiently waterlogged to resist movement by river currents may be removed from the channel.

C. Rooted Trees. No rooted trees, whether alive or dead, should be cut unless:

1. They are leaning over the channel at an angle greater than 30° off vertical and they are dead or dying or have severely undercut or damaged root systems or are relying upon adjacent vegetation for support and it appears they will fall into the channel within one year and create a blockage to flows; or
2. Their removal from the floodplain is required to secure access for equipment to a point where a significant blockage has been selected for removal.

D. Small debris accumulation. Small debris accumulations should be left undisturbed unless they are collected around a log or blockage that should be removed.

E. Sediments and soils. Major sediment plugs in the channel may be removed if they are presently blocking the channel to a degree that results in ponding and dispersed overland flow through poorly defined or nonexistent channels and, in the opinion of appropriate experts, will not be removed by natural river forces after logs and other obstructions have been removed.

III. Work Procedures and Equipment to be Used

A. Log removal. First consideration will be given to the use of hand operated equipment to remove log accumulations. When the use of hand operated equipment is infeasible, vehicle equipment may be used under the following restrictions and guidelines:

1. Water-based equipment should be used for removing material from the streams. A small crawler tractor with winch or similar equipment may be used to remove debris from the channel to selected disposal points.
2. When it can be demonstrated that stream conditions are inadequate for the use of water-based equipment, the smallest feasible equipment with tracking systems that minimize ground disturbance will be specified for use. Larger equipment may be employed from non-wooded areas where cables could be stretched down to the channel to drag out materials to be removed.
3. Access routes for equipment should be selected to minimize disturbance to existing floodplain vegetation, particularly in the riparian zone. Equipment should be selected which will require little or no tree removal to maneuver in forested areas.

B. Rooted trees. Whether dead or alive, rooted trees selected for removal shall be cut well above the base, leaving the stump and roots undisturbed. Procedures for removing the felled portion will be the same as for other logs.

C. Log disposal - general. All logs or trees designated for removal from the stream or floodway shall be removed or secured in such a manner as to preclude their re-entry into the channel by floodwaters.

D. Sediment blockages. The magnitude of the blockage necessitates the use of conventional excavating equipment. This equipment should be employed in a manner which will minimize environmental damages.

1. Access routes for equipment should be selected to minimize disturbance to existing floodplain vegetation, particularly the riparian zone.
2. Material disposal and necessary tree removal should be limited to one side of the original channel at any given location.
3. To the maximum extent possible, excavating equipment should be employed in the channel bed.
4. Where feasible, excavated materials should be removed from the floodplain. If floodplain disposal is the only feasible alternative, spoil should not be placed in any tributary or distributary channels which provide for ingress and egress of waters to and from the floodplain.
5. No continuous spoil pile should be created. It is suggested that no pile exceed fifty (50) feet in length or width and a gap of equal or greater length should be left between adjacent spoil piles.
6. Spoil piles should be constructed as high as sediment properties allow.
7. The placement of spoil around the bases of mature trees should be avoided where possible.

IV. Reclamation measures

All disturbed areas should be reseeded or replanted with plant species which will stabilize soils and benefit wildlife.

mental benefits derived from preserving the natural stream alignment and maintaining the habitat value of riparian vegetation.

4.3 STREAM IMPOUNDMENTS

There are two general reasons for impounding streams during coal mining operations. First, with the passage of SMCRA in 1977, a much greater emphasis has been placed on control of water quality degradation due to erosion and sedimentation. Disturbed land surface runoff is directed to detention basins, which due to topographic restraints, are sometimes constructed in ephemeral, intermittent or under some circumstances in small perennial stream beds.

The second category of stream impoundments associated with mining are those constructed to supply water for coal processing, dust control or other operational requirements.

Other types of impoundments include final cut or incline lakes created by the final land configuration of surface mined areas and dry dams built on ephemeral streams to keep surface runoff from entering a mine site.

Controlling streamflow through the use of impounding structures can have both detrimental and beneficial aspects to fish and wildlife resources. There are numerous impacts associated with indiscriminate regulation of flows on fisheries including interference with fish migration, reproduction, production, and the quality and quantity of available stream habitat (Peters, 1982). Conversely, operating impoundments to augment low flow downstream conditions can substantially improve fish survival. In addition, creation of impoundments can enhance wildlife and waterfowl habitats since this component in their habitat requirements is often the factor controlling their distribution.

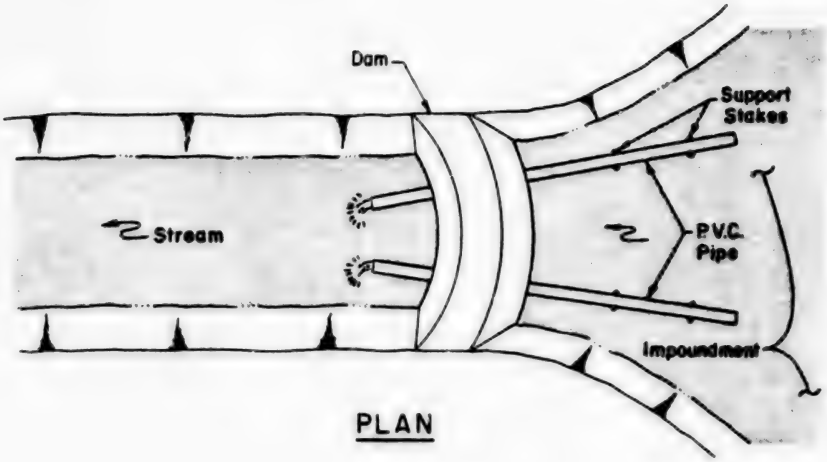
The primary consideration with regards to fish habitat in the construction of stream impoundments is maintaining adequate downstream flows. The U.S. Fish and Wildlife Service Cooperative Instream Flow Service Group in Fort Collins is currently involved with developing methods to determine the flow needs of various fish species (e.g. Stalnaker, 1978). In general, ponds constructed for sediment removal and the small water supply impoundments developed for mining operations are better suited for enhancement of wildlife than as a fisheries resource. Techniques for improving wildlife habitat and creating wetland areas have been documented (Ohlsson, et al. 1982). The types of enhancement practices available to the operator include constructing the ponds with gradually sloping rather than steep sides, introducing aquatic vegetation suitable as a food source, constructing waterfowl nesting islands and manipulating water levels seasonally.

These ponds could be used to augment low flow periods. A technique utilized by the New Hampshire Fish and Game Department on beaver ponds should also be applicable to the small ponds built on mine lands. The following general installation techniques apply to the placement of slotted plastic sewer or water pipes through small dams to provide flows when the ponds are not discharging through the spillways as outlined on Figure 4-22 (Kerr Wood Leidal Associates Ltd. and D. B. Lister & Associates Ltd., 1980):

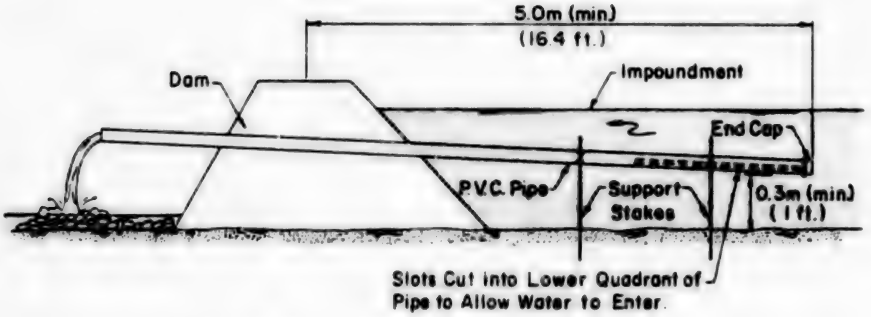
a. Pipes should extend a minimum of 5 m (16.5 feet) into the pond with a minimum slope of 4 percent towards the bottom. The distance between the bottom of the pipe and the pond bottom must not be less than 0.3 m (1 foot).

b. The pipe should be placed through the dam where the depth of the pond is greatest.

c. The area of the slotted inlet section should be at least twice the cross-sectional area of the pipe. With plastic pipe, 3 mm (one-eighth inch) slots can be readily cut into the wall with a multiblade saw.



PLAN



CROSS SECTION OF IMPOUNDMENT

Figure 4-22. Augmenting low flows by pipe withdrawal of pond water (Adapted from Kerr Wood Leidal Associates, Ltd. and D. B. Lister and Associates, Ltd., 1980).

d. Installation must be inspected a few days after the initial installation to check for correct operation, and thereafter approximately once each month for periodic maintenance.

e. A modification of this technique utilizes flexible, high density polyethylene pipe to syphon the water over the dam. This avoids altering the structural integrity of the impounding structure.

Consideration should also be given to providing protection at the outlet of the pipe in the form of riprap or other energy dissipators so that the downstream toe of the dam is not undermined by the discharging pipe.

Final cut impoundments, although conceivably related to stream alterations when they intercept streams, are not addressed in this document. The reader is referred to a recent manual published by the Office of Surface Mining which presents the planning and management aspects of mine-cut lakes at surface coal mines (R. Wayne Nelson & Associates, 1981).

4.4 STREAM CROSSINGS

Traversing streams is often associated with coal mining operations to provide access to facilities, transport coal or coal processing wastes and to move equipment around the site. Haul and access roads, whether they are for logging and timbering operations, farm and forest roadways or for coal mines, share common characteristics in their design and construction. Several references address fish and wildlife considerations and present measures to protect these resources for roadway stream crossings (U.S. EPA, 1975; Hynson, et al. 1982; Bell, 1973; Kerr Wood Leidal Associates Ltd. and D. B. Lister & Associates Ltd., 1980; Nelson, et al. 1978). The following discussion is based on these publications and the reader is referred to them for additional details.

When faced with a stream crossing during the design of a haul or access road, a number of factors should be analyzed (U.S. EPA, 1975):

- The hydraulic capacity that will be required.
- The potential for debris clogging the inlet.
- The bank protection measures necessary.
- The effects of changing the channel on upstream and downstream conditions.
- The amount of excavation or foundation work required.
- The type of streambed material.
- The timing of construction relative to high water.

There are basically three types of stream crossings: fords, bridges and culverts. Selection is based on stream size, debris potential, vertical position of the road relative to the stream, foundation conditions, construction and maintenance costs and contemplated road use and life.

4.4.1 Fords

Stream fords are unsuitable for most coal mining activities due to the type and size of equipment utilizing haul and access roads. They are used primarily during the exploration phase of mining when temporary stream crossings may be necessary to gain access to remote areas. Under these circumstances, selection of a defined crossing area and use of a gabion support structure at the crossing is suggested to reduce the impact on the stream as shown on Figure 4-23 (U.S. EPA, 1975). Generally any impacts to aquatic organisms are restricted to the immediate area of the ford.

4.4.2 Bridges

Of the three stream crossing alternatives (i.e., fords, culverts, bridges), bridges offer the least amount of obstruction to fish passage, the least use of fill within the water limits and usually the least amount of alteration to the stream bottom (Hynson, et al. 1982). Realistically,

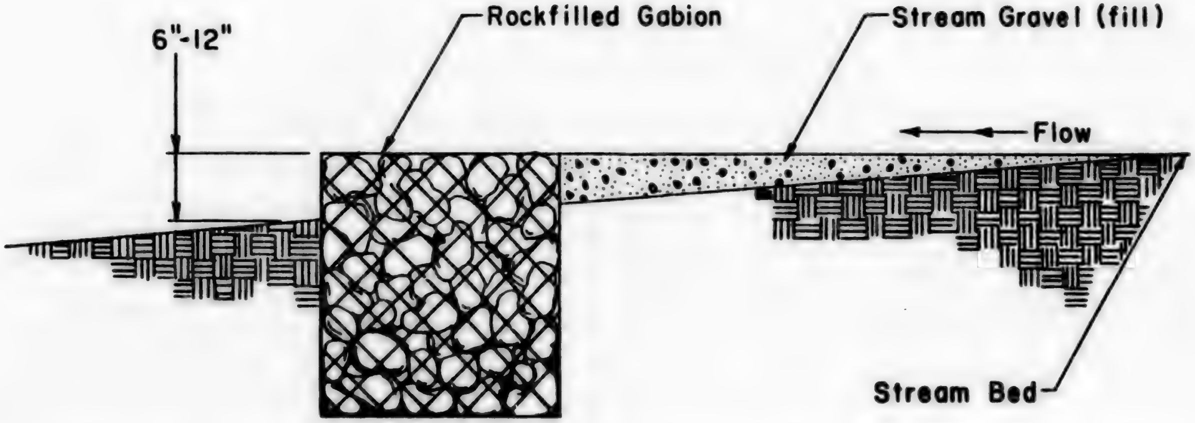


Figure 4-23. Stabilized stream ford crossing (from U.S. Environmental Protection Agency, 1975, as adapted by Hynson, et al., 1982).

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however, the cost of erecting a bridge must be justified by sensitive environmental conditions such as the presence of a high quality fishery in the stream, by loading requirements of equipment movements at the site or by the size of the stream. Several environmental design features can be incorporated into the design of bridges including (Hynson, et al. 1982):

- Avoiding constriction of the channel.
- Locating piers and other support structures out of the active channel bed.
- Including bank stabilization measures to avoid erosion of the bridge.
- Placing support structures in such a fashion that they do not impede movements of wildlife along the floodplain.
- Avoiding use of concrete aprons which spread out streamflow and create water too shallow for fish passage.

Although bridges are often not economically feasible, their use as temporary crossings in environmentally sensitive settings such as trout streams or wetlands can be the most acceptable alternative if suitable construction materials are readily available. An example of a temporary crossing using locally available trees to provide a low cost bridge design is the log stringer bridge suggested by Hynson, et al. (1982). Figure 4-24 depicts a log stringer bridge. The tops of the logs serving as stringers are slabbed off flat to provide the proper surface. Three-inch planks or poles laid across the stringers comprises the decking with running planks (three inches thick) placed over the floor lengthwise and parallel to the stringers. Wheel guards are placed at the outer edges of the deck, and strips of asphalt paper can be placed between stringers and decking to shed water. No materials with a tendency to collect water should be used as surfacing material, and a proper foundation for the bridge seat must be supplied. This type of bridge should not serve as a permanent structure since it will degrade, but it should be used when repeated stream crossings are necessary to install a permanent culvert or bridge (Hynson, et al. 1982).

4.4.3 Culverts

Use of culverts to pass streams under roadways can be the most economical and environmentally sound selection if properly designed and installed. Table 4-4 presents the shapes and size ranges of corrugated conduits that are used as culverts to pass streams under roadways. Proper size selection and installation procedures can be found in federal and state highway manuals or in texts such as the "Handbook of Steel Drainage and Highway Construction Products" (American Iron and Steel Institute, 1971).

In addition to the engineering principles involved with culvert design, several environmental aspects should also be considered, especially when culverts are to be placed in streams that support a viable fish population, or serve as a migration and spawning route. Factors governing fish passage through a culvert are: (1) water velocity and depth in the culvert, (2) length and slope of the culvert, (3) exit and entrance conditions, and (4) size and species of fish using the stream. Therefore, proper sizing of a culvert should not be the only factor considered. Additional considerations are:

- Selection of culvert type - The structural plate arch is recommended because it retains the natural streambed and if properly sized it allows for the natural depths and velocities which are more condusive to fish passage (Hynson, et al. 1982). However, by embedding a pipe arch culvert in the stream bottom (see Figure 4-25), the same effect can be obtained.
- Culvert gradient - One suggestion calls for setting the culvert as

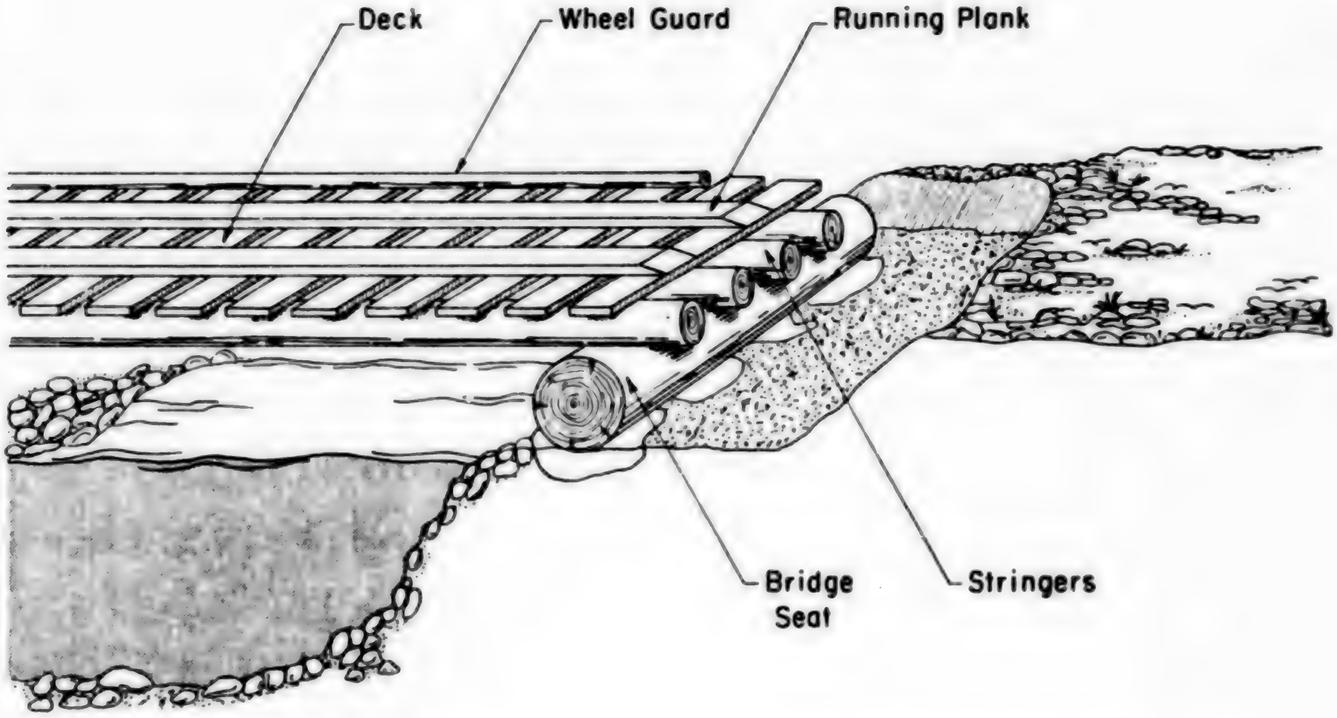

Figure 4-24. Log stringer bridge for use during temporary stream crossings (Adapted from Hynson, et al., 1982).

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Table 4-4. Common shapes and sizes of corrugated conduits (Adapted from American Iron and Steel Institute, 1971).

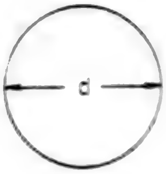
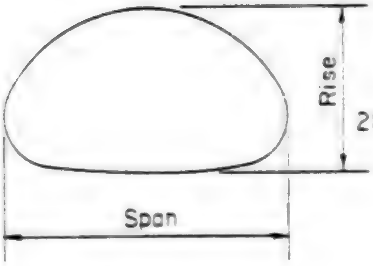
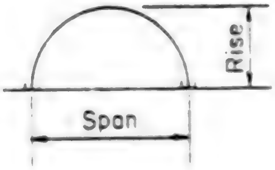
TYPE	DIAGRAM	RANGE OF SIZES
1. Round		6 in to 21 ft.
2. Pipe - arch		Span x rise 18 in. x 11 in. to 20 ft 7 in. x 13 ft. 2 in.
3. Arch (Structural plate)		Span x rise 6 ft x 1 ft. 9 1/2 in to 25 ft x 12 ft. 6 in

Figure 4-25. Pipe arch culvert embedded in a stream at an underground coal mine site in Utah.

close as possible to a gradient approaching zero (Bell, 1973). Other researchers suggest a range of slopes based on culvert length (Dane, 1978). For culverts longer than 24.4 m (80 feet), the effective slope (defined as the mean gradient of the water surface profile between a point located at the culvert inlet and the tailwater control point below the culvert outlet) should not exceed 0.5 percent unless baffles are added within the culvert. For shorter culverts, gradients should not exceed 1 percent without baffles.

- Selection of multiple culverts - To improve fish access, two or more culverts can be installed at different elevations, thereby accommodating a wider flow range. The higher culvert would be capable of conveying peak flows, while the lower culvert, preferably embedded in the streambed would ensure fish passage during periods of low discharge (Kerr Wood Leidal Associates Ltd. and D. B. Lister & Associates, Ltd., 1980). This permits the use of smaller culverts which increases flow depths within the culvert.

In situations where the culvert is not embedded in the streambed or where high velocities (averaging greater than 3 to 4 feet per second) occur in the culvert, provision for an outlet pool to promote fish passage and provide a resting area should be considered. Figure 4-26 illustrates such an arrangement. Since this creates backflooding, the culvert must be oversized to still maintain the design discharge capacity. Oversizing also provides the added benefit of promoting passage of debris which can clog the culvert and inhibit fish passage in the downstream direction.

Construction of a culvert will involve the temporary diversion of the stream. Figure 4-27 provides the construction sequence involved in this procedure. It is suggested that culverts be put in place from the downstream end to upstream, which allows surface waters to flow in a finished channel (U.S. EPA, 1975).

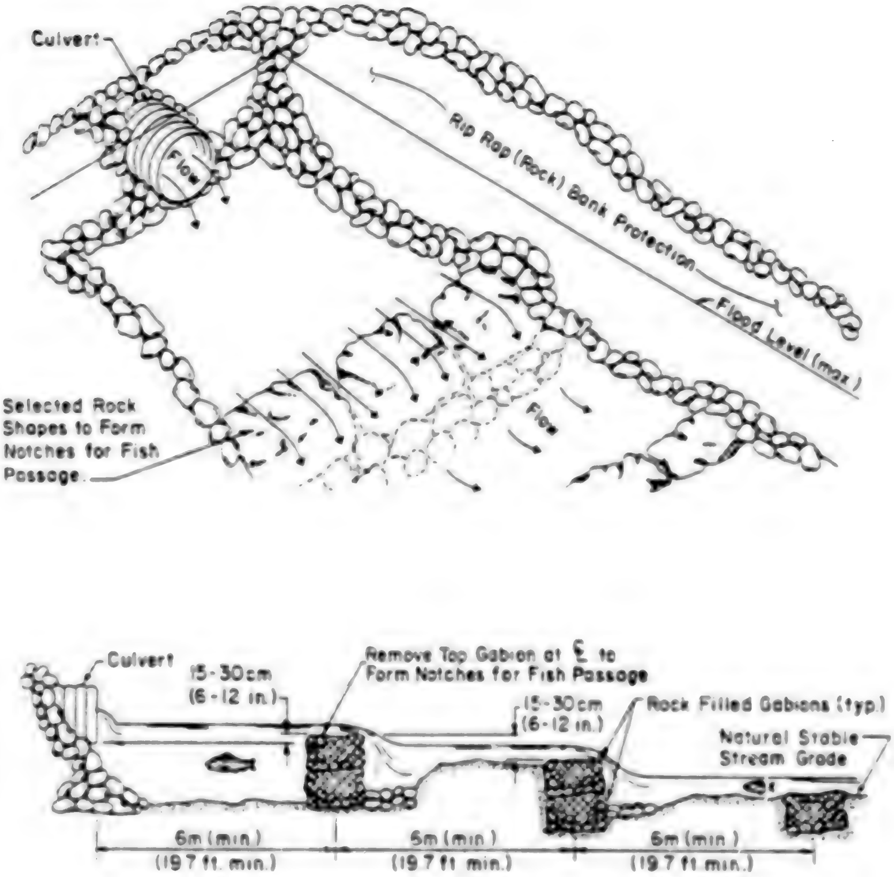
4.5 WATER QUALITY PRACTICES

Recent legislation and subsequent regulations governing coal mining have emphasized prevention of stream or lake alterations due to water quality degradation. In particular, control of erosion and of mine drainage by specifying mining practices and establishing effluent limitations which dictate treatment for sediment-laden surface runoff from disturbed areas and acid or toxic mine drainage are now in effect in all of the coal producing states. Consequently, the severe water quality alterations that characterized stream conditions from runoff associated with surface mined lands and from drainage of underground mines in the past should, in large part, be eliminated from future situations.

Numerous references and manuals have been prepared to address erosion and sediment control procedures on surface mines as well as the control, abatement and treatment technologies for mine drainage. In addition, many of the techniques presented in manuals on erosion and sediment control for construction activities and highways are also applicable to coal mining sites. A list of references that discuss general practices to protect stream water quality is included in the References section at the end of this chapter.

4.5.1 Erosion and Sedimentation

An effective erosion and sedimentation control scheme is based on prevention or minimization of erosion rather than the treatment and removal of suspended materials. Techniques to accomplish this include proper grading to eliminate steep or unstable slopes, rapid revegetation of disturbed areas and diversion of surface runoff away from disturbed areas. Sediment trapping devices provide temporary protection to streams until disturbed areas are stabilized and revegetated. Figures 4-28 through 4-30 depict measures applied at coal mines to reduce suspended solids carried in runoff


Culvert
Flow
Rip Rap (Rock) Bank Protection
Flood Level (max.)
Selected Rock Shapes to Form Notches for Fish Passage
Flow
Culvert
15-30cm (6-12 in.)
Remove Top Gabion at ℄ to Form Notches for Fish Passage
15-30cm (6-12 in.)
Rock Filled Gabions (typ.)
Natural Stable Stream Grade
6m (min.) (19.7 ft. min.)
6m (min.) (19.7 ft. min.)
6m (min.) (19.7 ft. min.)

PROFILE ON CENTERLINE (℄) OF CULVERT
TWO STEP GABION (OR ROCK) CONSTRUCTION

Figure 4-26. Culvert outlet pool formation to promote fish passage (Adapted from Kerr Wood Leidal Associates, Ltd. and D. B. Lister and Associates, Ltd., 1980).

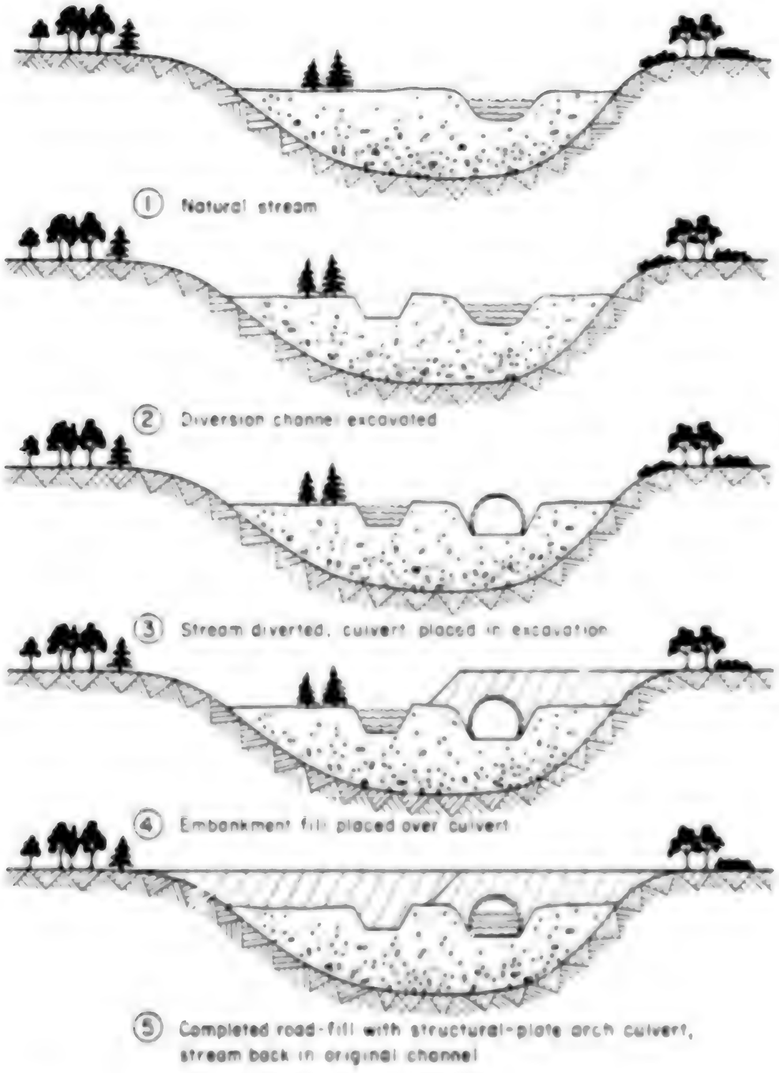

① Natural stream
② Diversion channel excavated
③ Stream diverted, culvert placed in excavation
④ Embankment fill placed over culvert
⑤ Completed road-fill with structural-plate arch culvert, stream back in original channel

Figure 4-27. Culvert installation procedure (Adapted from R. Wayne Nelson and Associates, Inc., 1982).

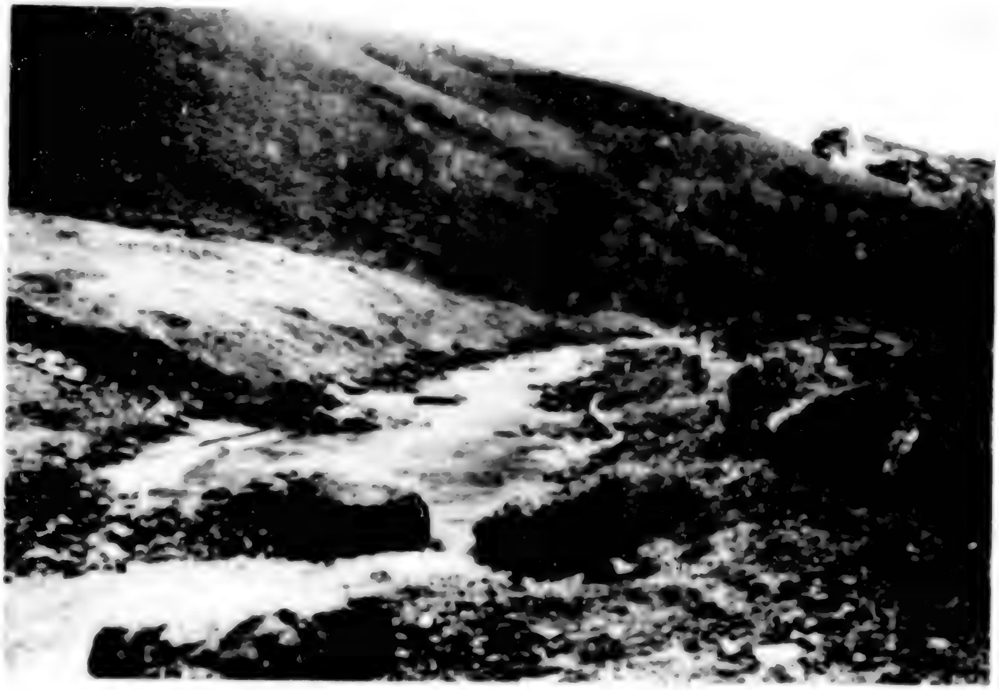


Figure 4-28. Stream protected by straw bales to prevent excessive sedimentation at a mine site in Utah.

Figure 4-29. Silt fence used to control sediment in surface runoff at an underground coal mine in Colorado.

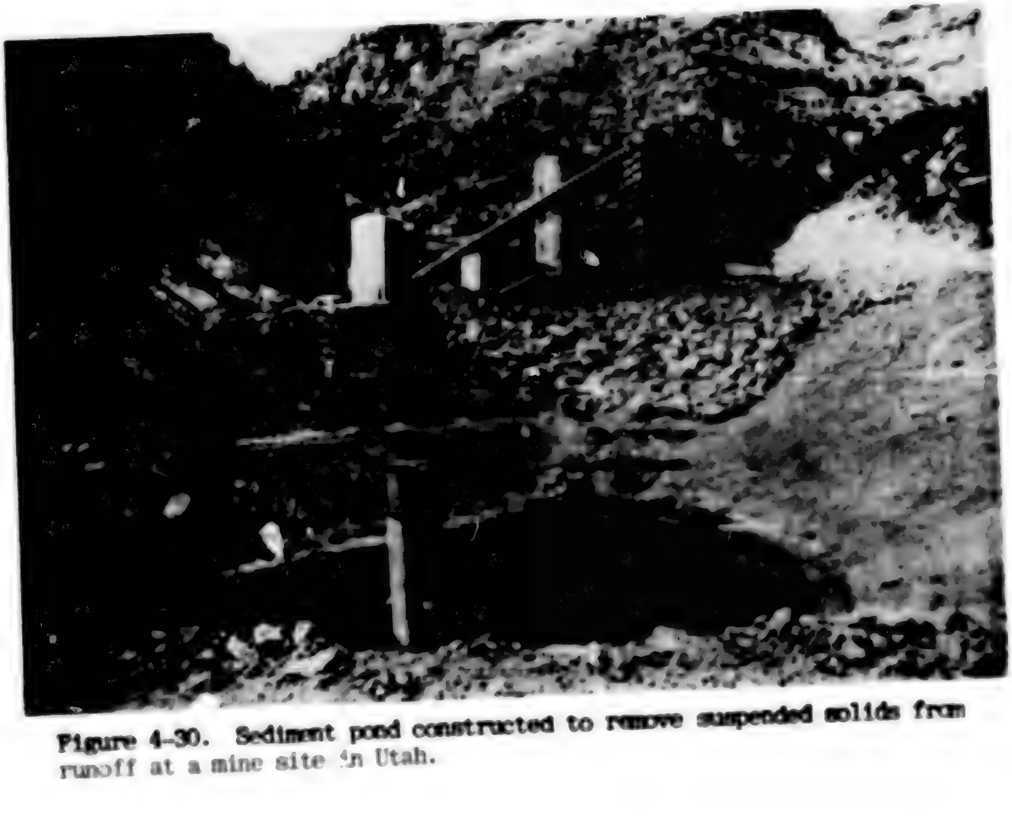


Figure 4-30. Sediment pond constructed to remove suspended solids from runoff at a mine site in Utah.

from the site. In addition to techniques such as straw bales, silt fences and sedimentation ponds, sediment removal through the use of vegetative filters has been examined by Albrecht and Barfield (1981), Hayes, et al. (1979), Kao, et al. (1976), Kouwen and Li (1980) and Karr and Schlosser (1977). These references suggest that through increased infiltration and flow retardance of surface runoff, vegetation can be effective in reducing the suspended solids concentrations as long as flows do not flatten it down. Thus stream buffer zones not only preserve riparian vegetation for wildlife habitat and aesthetic values, but also serve to reduce suspended materials reaching the stream.

For high quality waters, conventional erosion and sediment control practices may not sufficiently reduce suspended solids. Under these circumstances chemical procedures to precipitate suspended solids may be warranted. Research is currently under way to develop suitable technologies and several projects conducted in laboratories and under field conditions indicate that total suspended solids can be reduced using chemical means (McCarthy, 1973; Foree and Tapp, 1979; Ettinger, 1980; Tapp, et al., 1980; Maneval, 1980). However, until these methods are refined under varying field conditions, their usage may not be justifiable unless other procedures cannot adequately protect stream water quality.

4.5.2 Mine Drainage

The subject of prevention, control and treatment of mine drainage has been extensively researched, especially in regard to the eastern and midwestern coal fields. As with erosion and sediment control, prevention of the formation of acid or toxic mine drainage is far more effective than treatment schemes to remove selected constituents that degrade water quality. Suggested preventive measures include:

- Identifying, segregating and isolating potentially toxic or acid forming overburden.
- Identifying abandoned mine workings that contain acid drainage so that during mine planning such areas can be avoided or some types of treatment of these waters can be proposed during mining operations.
- Reducing surface water infiltration into abandoned mine workings at the mine site by providing impermeable liners in streams and reclaiming subsidence areas.
- Diverting water around active pits and reducing contact time of water in the pit when mining has exposed geologic strata with a high acid or toxic forming potential.

Where mining is occurring in acid seams, treatment processes may be necessary to meet effluent limitations. A number of treatment options are available including lime, lime/limestone combination, sodium hydroxide (caustic soda) and sodium carbonate (soda ash). Selection of methodology will depend on the ability to centralize collection of drainage, power availability for mixing and aeration, chemical composition of the drainage and cost of reagents. The techniques applicable to surface mining were critiqued by Lovell, et al. (1980). Soda ash briquettes were reportedly the most realistic treatment. The briquettes are loaded in self-feeding, covered hoppers that permit the water flow to pass through a sluice containing the reagent. The authors report that commercial devices are available and that inexpensive substitutes using plywood construction are possible. The briquettes dissolve slowly and will maintain a pH level of above 6.0. Minimal labor requirements are necessary to achieve continuous and adequate treatment. An alternative design utilized on surface mines is to place the briquettes in 55 gallon, perforated drums. The drums are placed in defined drainage channels such as an outlet for a sediment basin so that all water passing through the channel must also enter the drum and come in contact with the briquettes.

In some instances high quality water discharges are required by the regulatory authority to prevent degradation of particular streams. Methods have been developed to purify mine drainage, but these methods are relatively expensive and they are not readily amendable to the mobile nature of surface coal mining. Included in these technologies are reverse osmosis, ion exchange, electrodialysis, crystallization and iron oxidation (Skelly and Loy, 1973). Land treatment of acid mine drainage on calcareous soils is also a possible alternative to discharging mine water to a stream (Lovell, et al. 1980).

Another treatment approach for streams that are adversely affected by highly acidic discharges is in situ neutralization. An example of this type of process is installation of limestone barriers across springs or streams (Yocum, 1976). In this study limestone barriers were placed in a low iron, acidic stream in southcentral Pennsylvania. These barriers were essentially minature porous dams set in the stream channel, that consisted of cores of crushed limestone held in place by heavy rock fills on the upstream and downstream faces. The study indicated that performance of the barriers was good during low flows in terms of reducing acidity and raising pH, but marginal performance was observed during the design (average) flow and they were totally ineffective during high flows. Major problems were sediment clogging, and iron or silt coatings on the reagent limestone. A similar field trial in Pennsylvania was described by Lovell, et al. (1980). The conclusion of this study was that this technique, although not applicable to major streams, may be effective in reducing iron and sediment if portions of streams are channeled through barriers. The constraints of the barrier suggest that nearly pure limestone is required to react with acidic drainage; limestone grain sizes should be selected to provide a high surface area, while still allowing for sufficient leakage to reduce erosion during flood flows; and, dissolved iron concentrations must be low to preclude coating of the limestone fragments in the barrier by iron precipitates. Both studies indicated that this approach is best suited to complement rather than replace more conventional acid mine drainage treatment processes.

Use of instream neutralization to treat mine drainage must be tempered by the consideration of neutralization by-products, specifically iron hydroxide flocs. One study noted that aquatic organisms were adversely affected downstream of a neutralization plant because of the floc settling out on the stream bed (Herricks and Cairns, 1974).

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CHAPTER 5 - TECHNIQUES TO ENHANCE AND REHABILITATE STREAMS FOR FISH AND WILDLIFE RESOURCES

Proper engineering, design and construction measures implemented for mining-related stream alteration projects will minimize the adverse environmental effects previously associated with these activities. The opportunity exists, however, to improve stream conditions for aquatic and terrestrial wildlife during these projects with only a minor effort by considering and including enhancement measures in the initial design stages. The additional costs involved with incorporating fish habitat improvement devices into a stream relocation can be only a fraction of the total cost of the project, particularly if the need is recognized early in the project and the necessary construction materials such as rocks, logs and boulders are set aside when the land is cleared or during excavation of the new channel. Indirectly these costs may be offset by lessening potential delays in the permitting process, since most regulatory agencies tend to be in favor of enhancement of natural resources. Property owners will also favor the enhancement of the stream, since the stream should provide more recreational benefits.

This chapter is intended to provide mine operators and others with ideas and suggestions when planning and initiating work on streams. Many of the techniques can also be retrofitted to existing stream reaches that have deficiencies in life requisites of aquatic life such as shelter or spawning areas, or which suffer from excessive sediment deposition or uniform shallow depths.

The key to successful improvement or enhancement of stream projects is to anticipate what conditions will exist as a result of the stream alteration project, analyze what deficiencies may exist for inhibiting or limiting the development of aquatic or terrestrial life under project conditions, and address corrective measures in the initial phases of the project, preferably during the preliminary design stage. This type of input should originate from a qualified fisheries biologist and/or wildlife ecologist, who should be part of the design team or who should at least review and comment on the design and construction details of the project.

5.1 - STREAM HABITAT ENHANCEMENT STRUCTURES

Fish habitat improvement structures are designed to utilize the natural processes of a stream, primarily with respect to the scouring action which is used to develop or rehabilitate stream sections to enhance their potential as a fishing resource. Fish have several basic requirements that must be met to survive or inhabit a particular stream reach. These needs include food, shelter and cover, acceptable water quality (pH, dissolved oxygen, temperature), minimum flow depths and spawning areas. Key physical factors are current velocity, flow type, substrate, available cover and habitat diversity (Hynes, 1970). The range of tolerance for each of these factors will vary among species. It has been found that various fish species will occupy different areas within a stream based on substrate type, depth of water and current velocities (Gorman and Karr, 1978). The purpose of habitat improvement devices is to modify these physical conditions such that the stream provides the necessary requirements for fish survival.

Types and Their Function

The use of habitat improvement devices increases diversity of habitat by providing shelter or altering flow, channel morphology and/or substrate composition (Swales and O'Hara, 1980). Devices installed on streams include current deflectors, low dams, artificial riffles or weirs, and artificial cover devices. The corresponding function of these structures are to restrict flow during low flow periods so that adequate depths are provided, vary the channel gradient by establishing riffles and pools, and provide shelter and cover for fish.

Due to the dynamic nature of stream systems and the complex interactions of the physical processes and the resultant effects to aquatic ecosystems, instream devices should not be placed in waterways without consultation with the appropriate state fish and wildlife agency. Modifications to stream channels and installation of devices within a floodway of streams may require a permit from the Army Corps of Engineers or the state agency handling stream encroachment projects. Coordination with the appropriate state and federal agencies is essential in the successful completion of a stream improvement project. These agencies have the staff and experience to assist operators in the design and implementation of instream habitat improvement practices.

Selection Criteria

Indiscriminate use of instream structures can be damaging to the stability of the stream channel, ineffective or detrimental to aquatic life, as well as costly and time consuming. Their application to a particular stream must consider both ecological and engineering factors.

Ecological considerations include the quality and quantity of water in the stream, the present or projected habitat deficiencies, and the potential for developing a fisheries resource. For example, a severely polluted stream or one that periodically dries up does not usually merit the efforts involved in installing current deflectors, but might warrant placement of random boulders. Habitat evaluation is also important since different structures provide different benefits (i.e., concentrating flow depths vs. providing cover) which may or may not be the factor limiting survival of various fish species in that stream.

Engineering aspects that need to be examined include the effects of the structure on the stability of the channel and flow conveyance. Instream structures, when properly designed and constructed, should not restrict flood flows nor should they cause streambank erosion.

The economics of stream improvement are dependent on the available manpower, equipment and materials. For example, log deflectors may not be as economically attractive as rocks if trees, surplus telephone poles or suitable substitutes are not readily obtainable.

It has been suggested that stream improvement projects be approached in a manner similar to typical construction projects, beginning with a feasibility study to collect information and produce preliminary alternative designs, followed by the final design phase (Shields, 1981). The design procedure would include:

1. Determination of habitat deficiencies (for the fish species present or desired).
2. Determination of the general location of each structure.
3. Select the types of structures.
4. Size the structures to produce the desired effect without altering the maximum flow capacity of the channel.
5. Evaluate the hydraulic effects of the structures under both high and normal flows.
6. Examine changes to the ability of the stream to transport sediment.
7. Select materials for construction.
8. Design the structure to withstand the expected maximum velocities and turbulence.
9. Provide construction inspection for proper installation.

5.1.1 Current Deflectors

Purpose

Current deflectors are multipurpose devices that protect streambanks; concentrate low stream flows; manipulate current direction within the channel; and, provide cover for fish. Protection of banks is accomplished by diverting flows away from unstable areas. Deflectors are designed to restrict the main channel under low discharge conditions, thereby providing aquatic organisms with deeper, faster-moving water which enhances their survival during these critical periods. With proper positioning, deflectors create within-channel meandering and cause selective scouring immediately downstream of the deflector tip. Holes and depressions resulting from the action of the deflectors provide fish with areas to rest and hide. In addition, these devices can be utilized by fish and other aquatic life as cover and as a surface for attachment by organisms that serve as food for fish. Successful performance is determined by proper installation which includes securely anchoring these structures into both the bank and bed of the stream and providing riprap protection where they join the bank.

Description

The most effective current deflectors are triangular-framed, rock-filled structures that project from the bank into the stream. Several variations of deflectors are depicted in Figures 5-1 through 5-5. Figure 5-6 provides general construction specifications for these structures regardless of the material used. Due to their low profile, stream deflectors are intended to be effective during low to normal flows, and to be overtopped during high discharge periods to prevent restriction of flood flows. Stream deflectors may be utilized singly (Figure 5-7), in pairs directly opposite each other (Figure 5-8), or in combination with other structures (Figure 5-9) to improve fish habitat and protect streambanks. The size of the structure is dependent on the normal stream width and should extend no further than one-third to one-half of the way across the stream. The channel should not be constricted to less than the narrowest natural stream width of the downstream unaltered stream reach. Although these structures were developed to enhance trout streams, they are also suitable for warmwater streams.

Equipment and Materials

- Framing material consists of the following - long, straight, durable 8 to 12 in. diameter hardwood logs or poles; gabion wire baskets; or large, flat rocks.

- Durable stone is used to fill the structure. For gabions, 4- to 8-inch diameter stone should be used. Larger stone, up to 12- to 16-inch stone for log or rock deflectors.

- No. 4 to No. 6 steel reinforcing rod (0.5 to 0.75 in. diameter) for anchoring logs.

- Trencher, backhoe or other equipment suitable for excavating narrow, deep trenches in the streambank.

Construction

a. First, the primary function of the structure should be determined. If it is to be used for erosion protection, the frame should be long enough to protect the eroded section of the bank. If it is to be used to narrow the stream, the frame should not restrict the stream to less than the narrowest natural width during normal flows or if two deflectors are located across from each other, the opening between them should be no less than the narrowest natural stream width.

b. Construct the triangular frame as shown in Figures 5-10 to 5-13. Gabions and logs should be anchored 6 to 10 ft. into the bank. To minimize erosion, the angle between the upstream end of the frame and the bank should be approximately 30° so that the current will be deflected toward

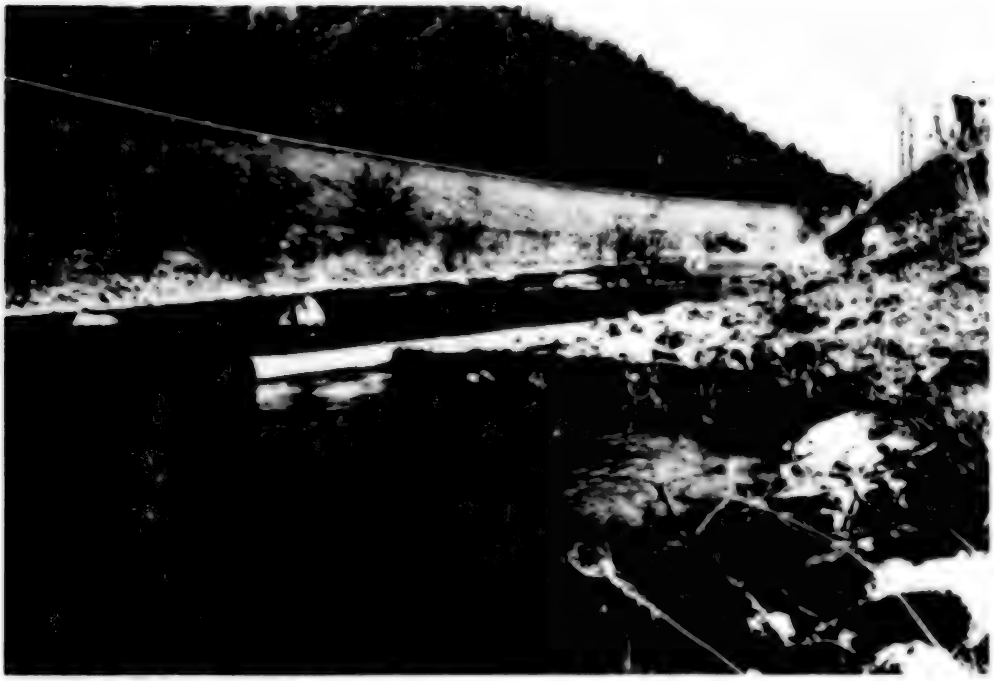


Figure 5-1. Log frame deflector in a relocated stream in Pennsylvania.

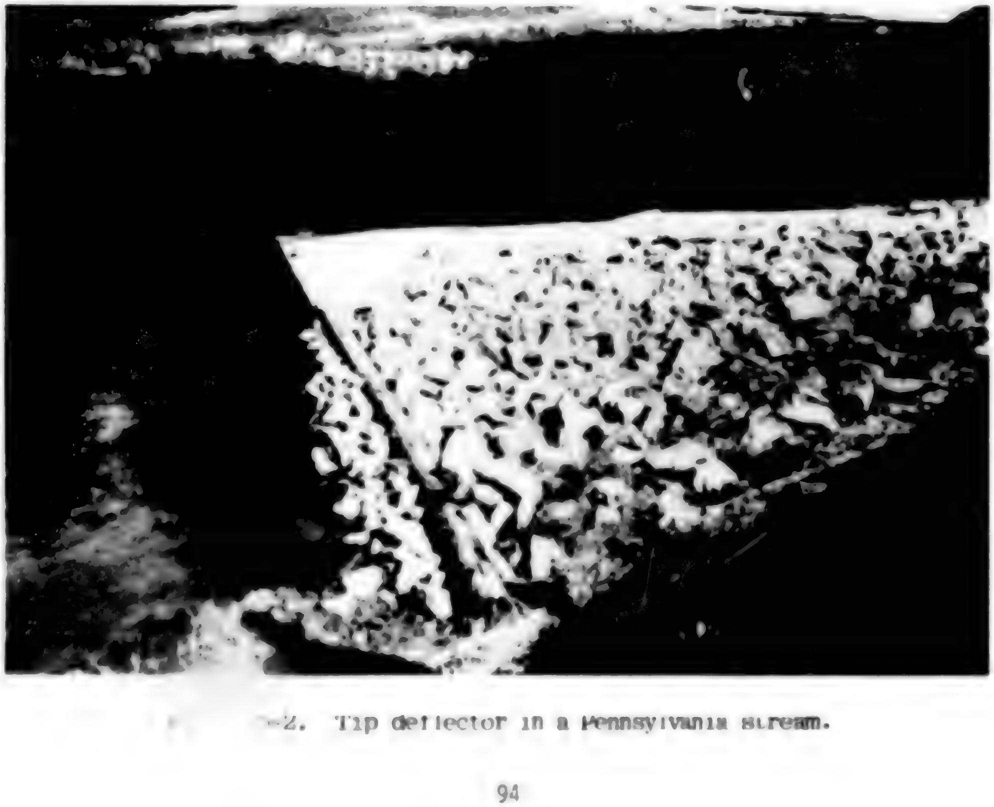


Figure 5-2. Tip deflector in a Pennsylvania stream.

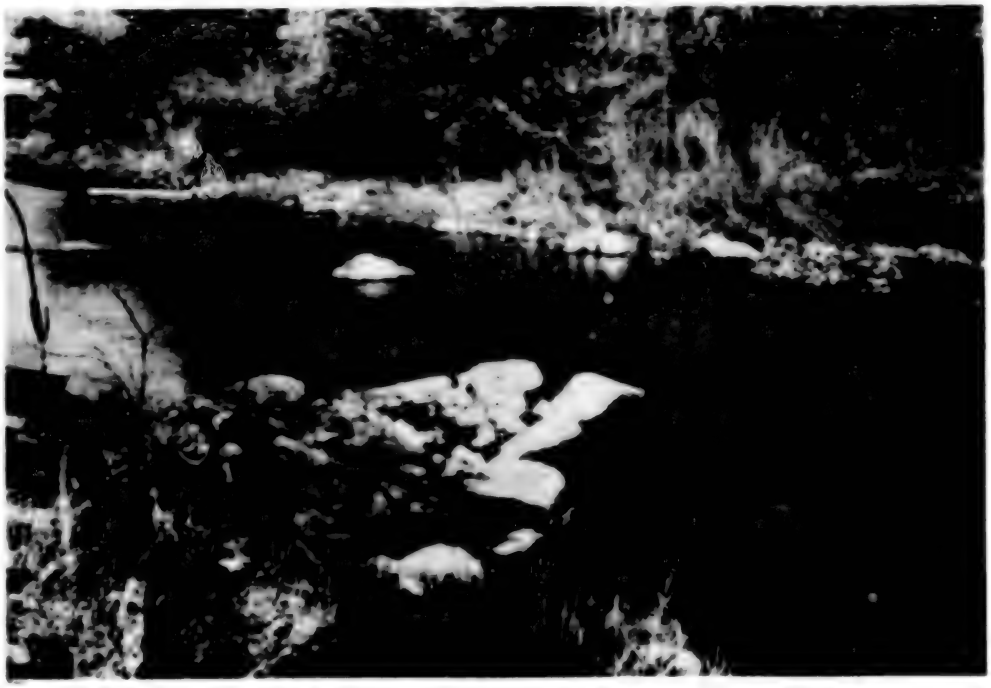


Figure 5-3. Rock deflector installed as part of a stream improvement project in Colorado.

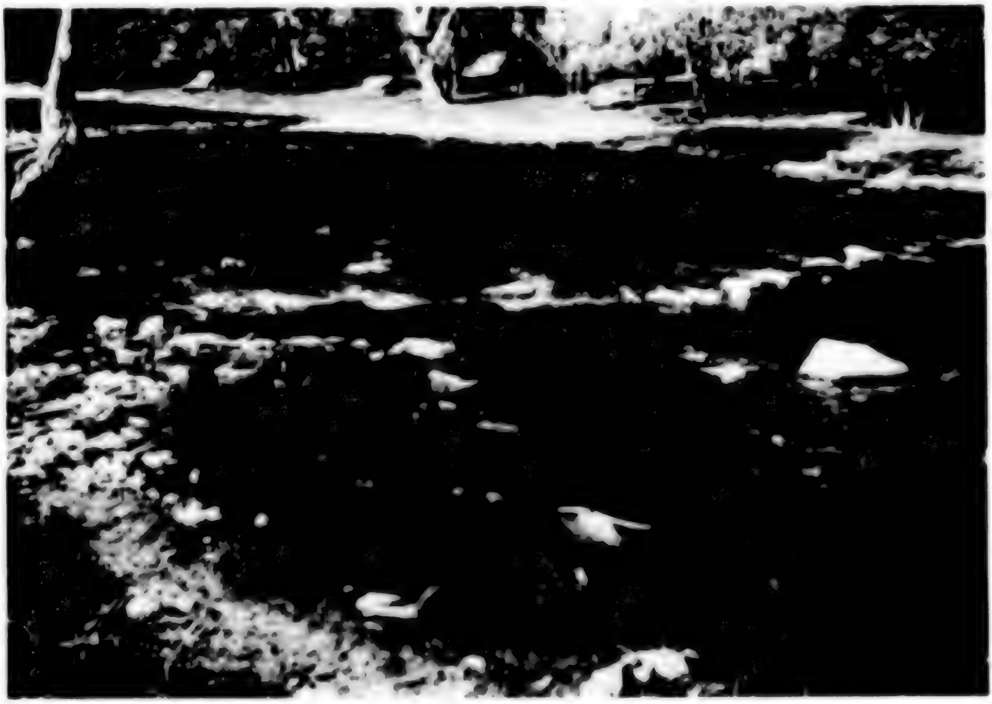


Figure 5-4. Rock deflector used at a stream improvement demonstration site in Pennsylvania.

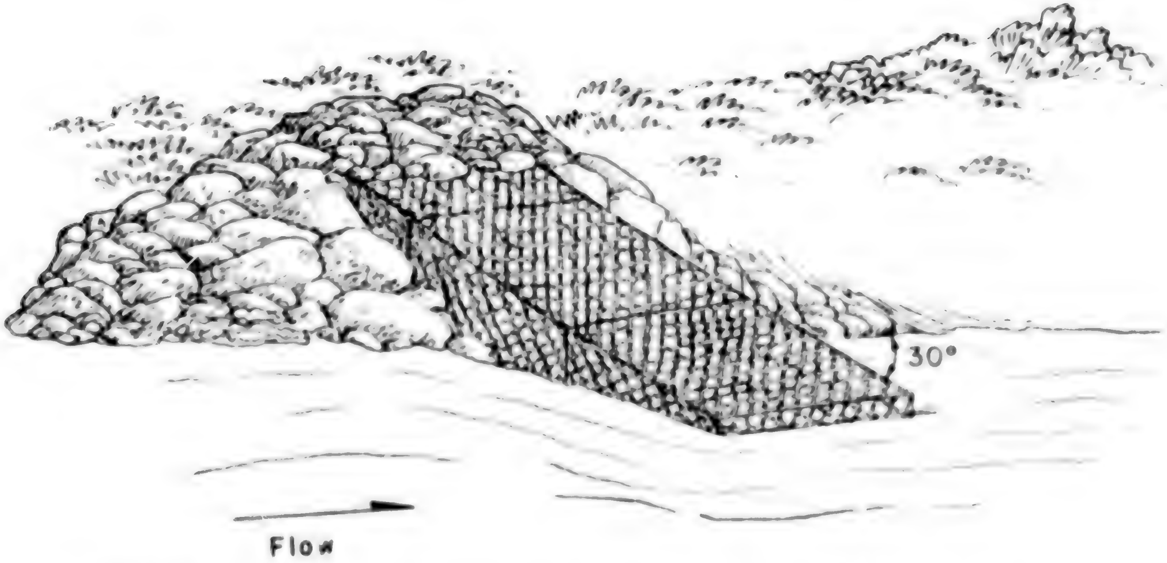
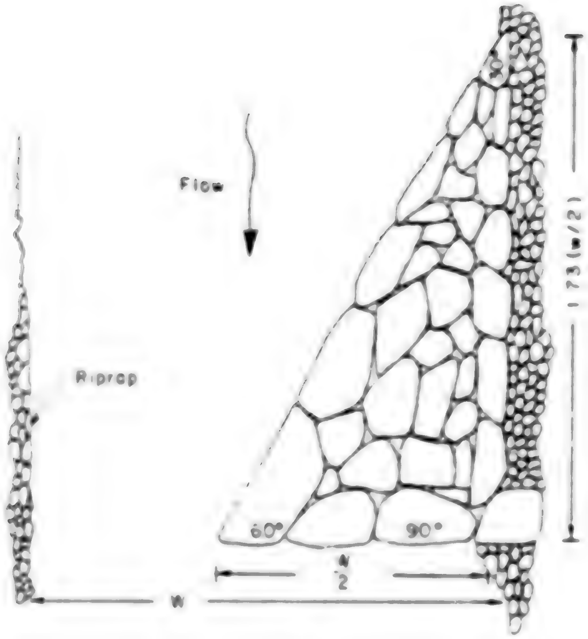


Figure 5-5. Gabion deflector (Adapted from Pennsylvania Fish Commission, 1980).



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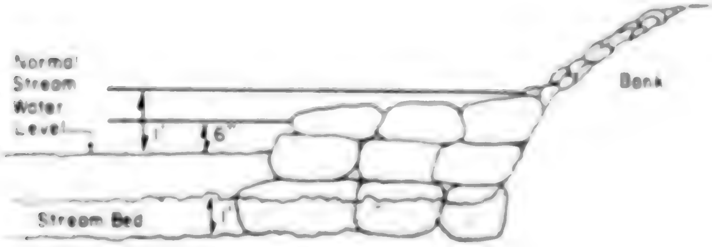


CROSS SECTION

Upstream View

Figure 5-6. Single wing deflector (Adapted from Wingate, et al., 1979).

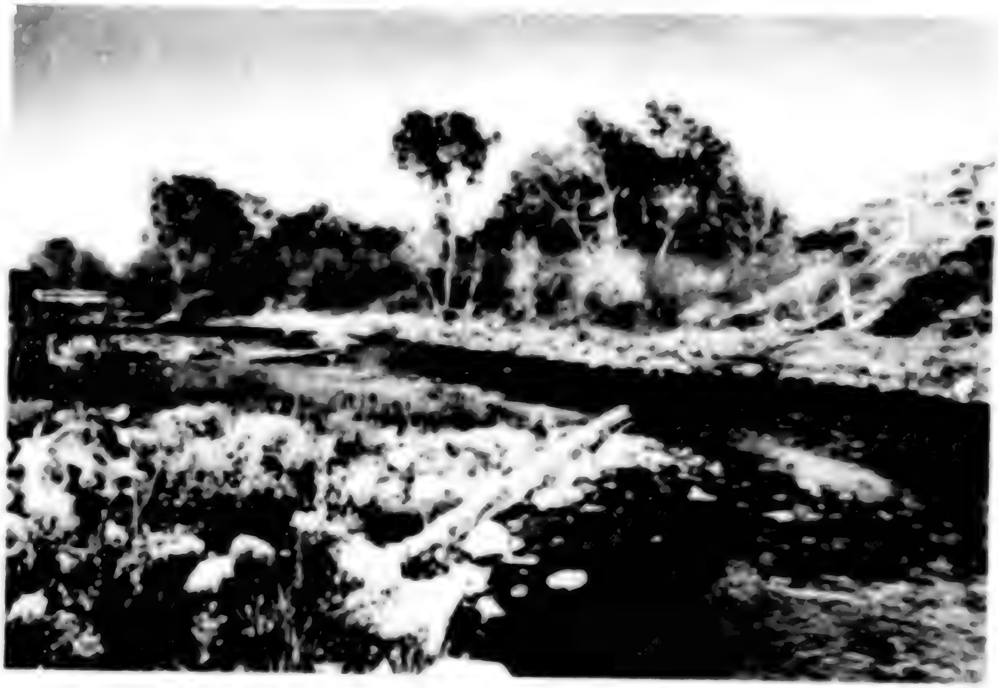


Figure 5-7. Single deflector formation in a Colorado stream.

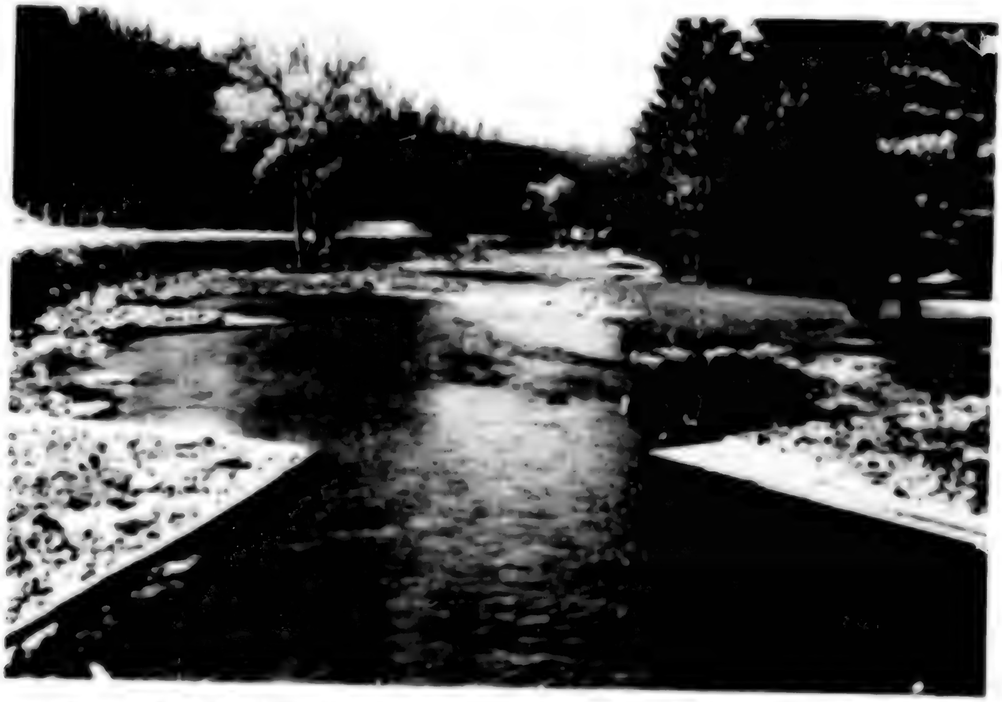


Figure 5-8. Paired deflectors arrangement in a Pennsylvania stream.

Figure 5-9. Deflectors used in conjunction with random boulder placement at a stream relocation project in Pennsylvania.

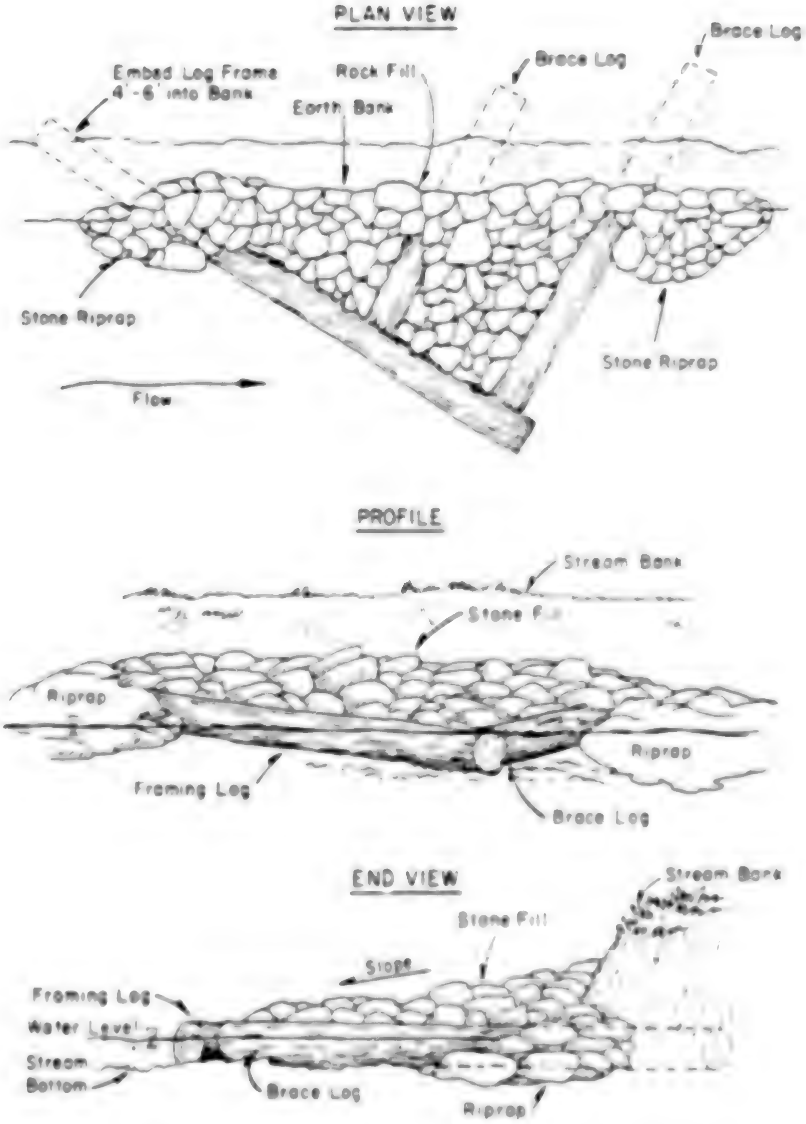
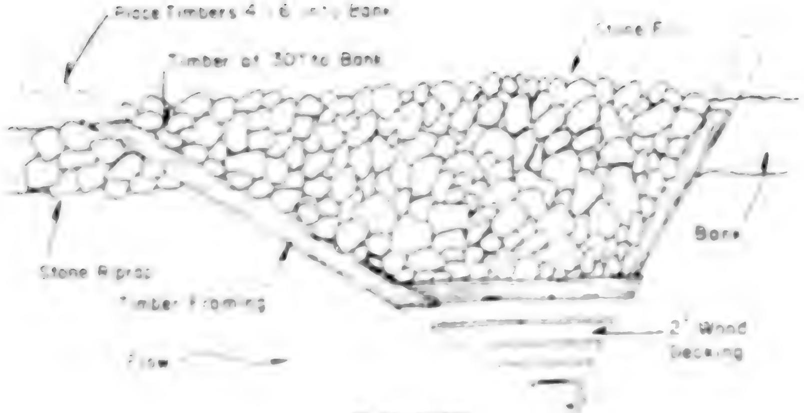
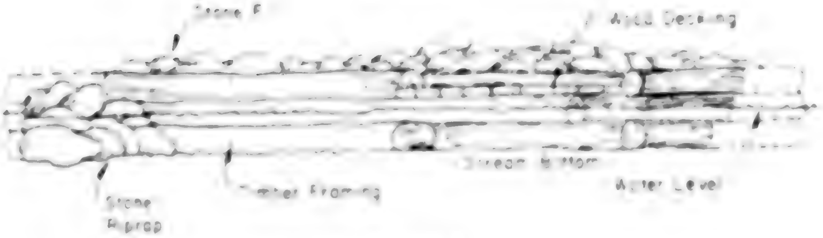


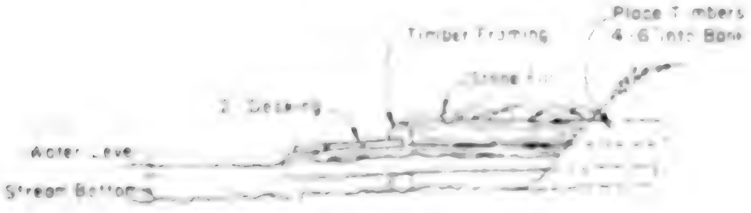
Figure 5-10. Log frame construction details (Adapted from Pennsylvania Fish Commission, 1980).



PLAN VIEW



PROFILE



SECTION

Figure 5-11. Tip deflector construction details (Adapted from Pennsylvania Fish Commission, 1986).

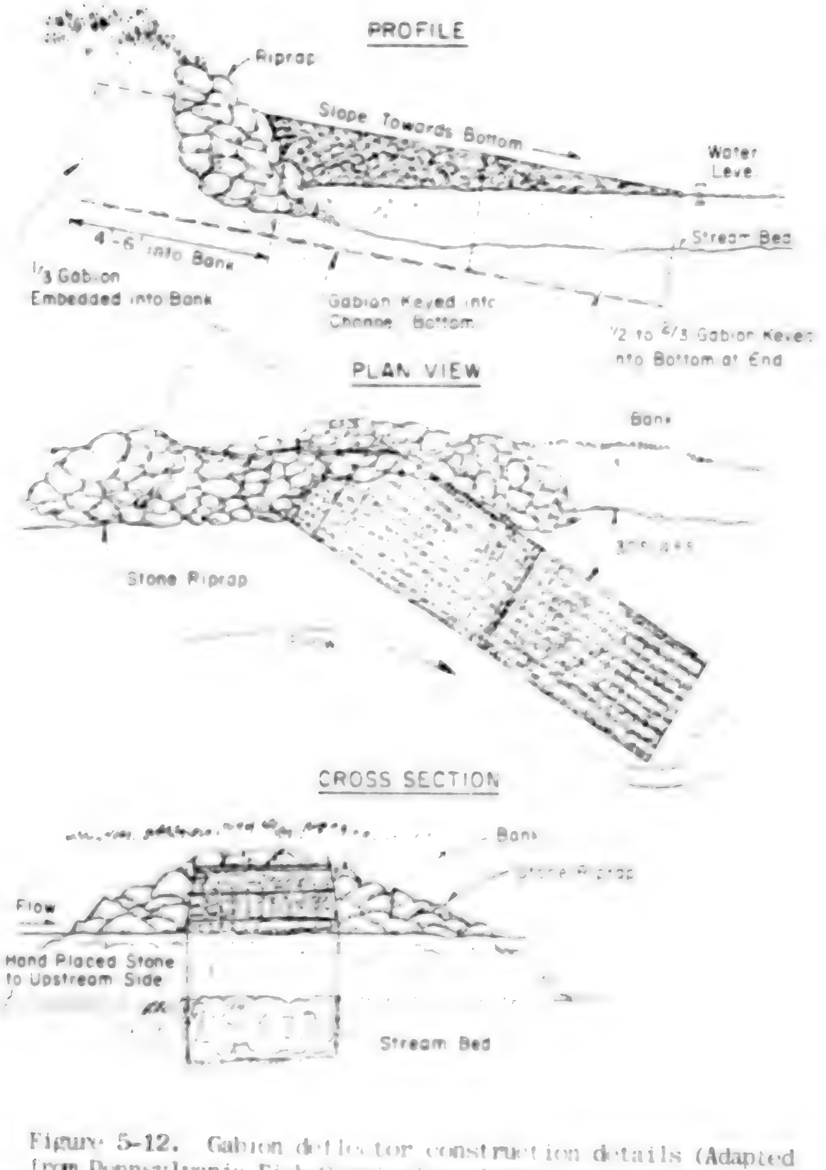


Figure 5-12. Gabion deflector construction details (Adapted from Pennsylvania Fish Commission, 1980).

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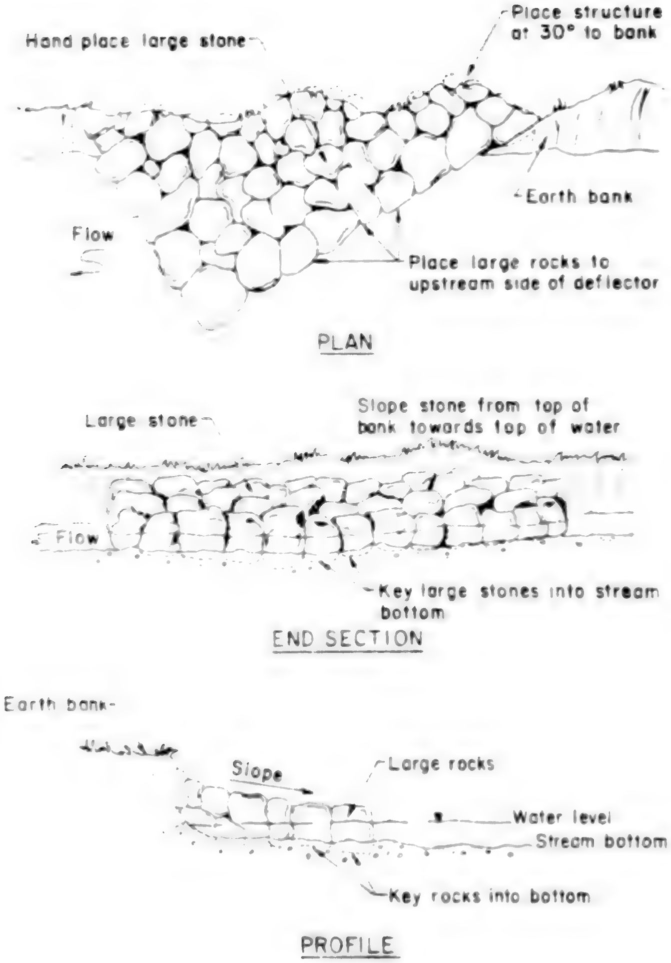
Hand place large stone
Place structure at 30° to bank
Earth bank
Flow
Place large rocks to upstream side of deflector
Large stone
Slope stone from top of bank towards top of water
Flow
Key large stones into stream bottom
Earth bank
Slope
Large rocks
Water level
Stream bottom
Key rocks into bottom

PLAN

END SECTION

PROFILE

Figure 5-13. Stone deflector construction details (Adapted from Pennsylvania Fish Commission, 1980).

the center of the stream rather than the opposite bank. The short side of the frame should face downstream.

c. Securely anchor the structure to the stream bed. For log frame deflectors, drill holes in the logs and pin them to the stream bottom and to each other with reinforcing rods. Gabion and stone frame deflectors should be embedded at least 1 foot into the stream bed.

d. Fill the frame with stone and place additional stone at the outer edges of the frame where it intersects the bank to prevent scour.

e. For tip deflectors, which are modified log frame deflectors, a triangular wooden deck constructed with 2-inch-thick planks is substituted at the corner of the device farthest from the bank. This deck is suspended above the stream bottom and serves as an overhang for additional fish shelter. The planks are nailed or pinned to the log frame for support (see Figure 5-11).

Maintenance

Properly constructed current deflectors require little maintenance, but they should be examined periodically to verify that they are functioning properly and are not causing erosion downstream. They should be checked after abnormally high discharges and after ice-out in the spring. Any missing stone should be replaced. The possibility of scouring at the junction where the deflector frame enters the bank should be checked. All log jams and accumulated debris should be removed to prevent changes in the current deflection and constriction of the channel.

Evaluation

Log frame and tip deflectors have been installed at numerous locations in Pennsylvania and have noticeably improved stream scouring and bank stabilization. During high flows, silt becomes trapped in the rock fill and natural revegetation subsequently occurs on such areas. The structures are unimposing due to their low profile and eventually blend into the streambanks so that their aesthetic appeal to fishermen is high. Tip deflectors provide additional cover and allow fish to hide beneath the suspended planks. It is suggested that treated logs be used to prevent decay which will occur as a result of alternating wet and dry conditions (Federal Highway Administration, 1979).

The use of gabions as deflectors has been reported to enhance fish habitat by creating pools and riffles, scouring silt laden streams, and consolidating low flows (Brusven, et al. 1974; Cooper and Wesche, 1976). The use of gabions is recommended in situations where other suitable materials are unavailable or where deflectors will be subjected to strong currents (Pennsylvania Fish Commission, 1980). The estimated life of gabions is in excess of ten years (Federal Highway Administration, 1979). Stone deflectors are susceptible to washout and their use should be confined to low gradient streams with relatively constant flows unless very large stones are available.

The potential for aquatic habitat enhancement by using these devices is excellent. The pools and riffles created and the concentration of flows during low water periods provide habitat for fish that would be nonexistent in wide, uniform gradient streams. Gamefish, in particular trout and smallmouth bass, can benefit from the creation of pools because they provide cover and shelter as well as the minimum depth requirements. The structures themselves will attract aquatic invertebrates. Aquatic organisms will inhabit the openings between the rocks, and rock surfaces will be available for organisms that must attach to objects to successfully colonize. These organisms, in turn, serve as a source of food for fish.

Relative costs are determined by the materials available. Stone deflectors are the least expensive and easiest to construct since they require only large stone for framing. Log deflectors are more stable and if log poles are available from clearing operations, material costs are limited to reinforcing rods. Gabions are the most expensive option, with plastic-coated wire baskets (recommended for stream usage) priced at $20 to $25 in 1981 for a 6 x 2.5 x 1 ft. gabion. Although gabions are aesthetically unpleasing, they are more stable and maintenance-free than other deflector devices.

The time required to completely install deflectors has not been quantified in the literature and will vary according to the deflector size, equipment availability, and experience of the crew. It was reported that it took three men, 4 hours to fill 6 gabions using shovels and a wheelbarrow during installation of a gabion framed deflector (Cooper and Wesche, 1976).

5.1.2 Channel Blocks

Purpose

Channel blocks divert braided channel flows into one main channel, thereby concentrating the water available during low discharge periods. For stream relocation projects, these structures could be used to permit the design of a narrower main stream channel while providing a separate channel adjacent to the main stream for flood flows.

Description

Channel blocks are barriers installed across portions of streams where the main channel divides into two or more separate channels. The water is then routed to a single channel during low flows. Channel blocks can be constructed of logs, gabions, or stone and should be limited in height such that they are below the streambank elevation to prevent the stream from overflowing and causing flood damage and erosion. To maintain the integrity of the structure during high flows when it will be overtopped, large rocks are placed behind the block to minimize scouring. A typical channel block is depicted in Figure 5-14.

Equipment and Materials

Log frame channel blocks require:

- Three 8 to 12 in. diameter logs long enough to span the channel with a surplus of 8 to 12 ft. for keying into the banks are preferred. However, shorter logs can be spliced together to achieve the same result.
- Durable stone fill, 6 to 12 inches in diameter.
- Shorter timber sections of the same diameter for cross bracing.
- No. 4 to No. 6 steel reinforcing rods (0.5 to 0.75 in. in diameter) for anchoring logs.

Gabion barriers require:

- Wire baskets of suitable size.
- Stone fill for baskets.

In addition, both structures will require a backhoe or trencher for bank excavation and leveling of the channel prior to installation (this may be accomplished by hand with shovels) and large rocks to be placed immediately behind the block.

Construction

Log Frame Channel Block

a. Excavate a trench on both sides of the channel wide enough to accommodate the log diameter, deep enough to match the stream bed, and 4 to 6 ft. into the bank.

b. Place one of the logs into the trench and pin it to the stream bed.

c. Follow the same procedure for the rear cross channel log that parallels the front log (Figure 5-15).

d. Pin cross braces to the tops of the in-place logs.

e. Lay the third cross channel log on the cross braces at the front of the structure and pin securely.

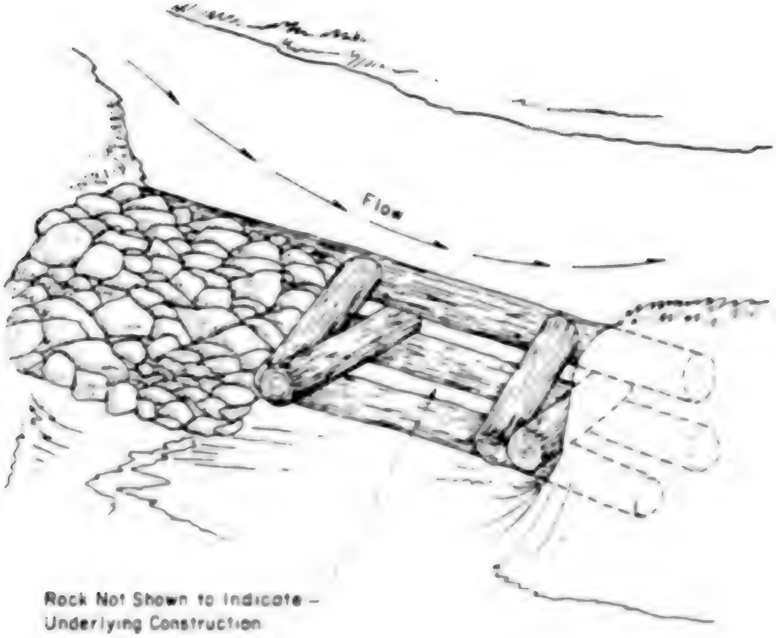

Figure 5-14. Typical channel block (Adapted from Pennsylvania Fish Commission, 1980).

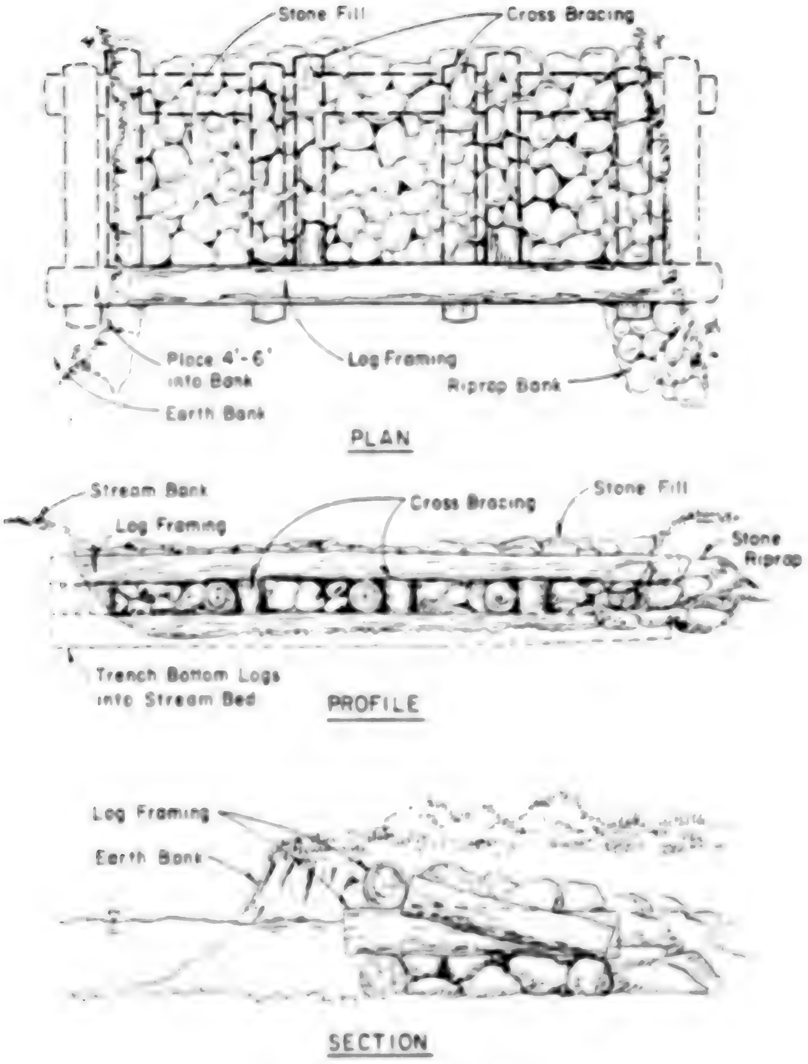

Figure 5-15. Log frame channel block construction details (Adapted from Pennsylvania Fish Commission, 1980).

f. Pin additional cross braces between the rear log and the top cross channel log.

g. Fill the structure with stone and place additional rocks behind it.

h. Backfill the trenches and compact to stabilize.

Gabion Barrier

a. Excavate cuts in both banks so that the gabions can be embedded 4 to 6 ft. into the banks on both sides of the stream.

b. Excavate a narrow trench across the channel that is about one-half the height and the same width as the gabions.

c. Place gabions across the channel and lace together.

d. Fill gabions with stone; pack and add additional stone until level with the top; and lace the lids on.

e. Add additional layers of gabions as needed to block the flow, but do not exceed the bank height.

f. Backfill and compact trenches in banks.

g. Place large rocks behind the gabion wall and riprap both banks where the gabions are anchored.

Maintenance

If properly constructed and securely anchored, no routine maintenance should be necessary. The channel blocks should be checked during and after several high water periods to determine that they are functioning properly and have not sustained damage.

Evaluation

For braided or multiple channel streams, these devices will concentrate flows and decrease the possibility of fish and other aquatic organisms becoming trapped in a channel that receives little or no water during low flows. Channel blocks aid in reducing water temperature fluctuations and can be used to direct flows to a better channel (U.S. Forest Service, 1969). From an aesthetics point of view, the log frame channel block would be preferred due to its natural appearance. Gabions will tend to entrap silt during flood flows and will eventually blend into their surroundings.

From an economic standpoint, the relative costs of the two types of channel blocks will be dependent on the stream size and availability of logs or stone fill for the gabions. Actual costs or manpower estimates will vary with the project size and location.

5.1.3 Cross-Channel Structures (Low Level Dams)

Purpose

The primary function of cross-channel structures, including log drop structures, rock check dams, split rock check dams and low flow channel structures (jack dams), is to cause scouring action below the device, thereby creating a deep hole. This type of habitat may be scarce on streams with a uniform gradient which commonly occurs in artificial channels designed and constructed for relocation projects. Creation of deep pools or scour holes provide a refuge that can be essential for fish survival during low flow conditions. The turbulence created as water flows over the dam serves to oxygenate the water, providing an additional benefit to fish.

Description

Numerous types of cross-channel structures have been installed as stream improvement devices. They range from gabion dams with spillways to a single log embedded in the stream. However, they all have several features in common. They are not designed to impound water and should not be used on low gradient streams because the pool formed behind the device may trap silt and debris, thereby losing its value as good habitat. These structures must be securely anchored due to the hydraulic forces acting on them and they should not be constructed on streams with flows exceeding 100 cubic feet per second without taking precautionary measures to ensure stability.

Two types of cross-channel structures are the "jack" and "log drop" dams (see Figures 5-16 and 5-17 respectively). Both types of structures can be easily constructed and should function properly on streams less than 20 ft. in width. The low flow channel structure or "jack dam" is designed to direct flows toward the center of the dam using wing walls, thus minimizing erosion at the ends of the device and prolonging its usefulness.

Rock check dams (Figure 5-18) can be constructed on streams of varying size as long as adjustments are made to the size of the rock used. The split rock dam (Figure 5-19) is best where large rock is needed to keep the dam in place and therefore blockage of fish migration is a potential problem.

Equipment and Materials

Jack Dam

- Six 8 to 12 in. diameter logs. Two of the logs should be long enough to span the stream with an additional 8 to 12 ft. for securing the ends into the streambank on both sides.
- Heavy wood planking (2 in. x 6 in.) for the floor and wing walls.
- No. 4 to No. 6 steel reinforcing rods (0.5 to 0.75 in. in diameter) to anchor logs.
- Stone fill/riprap. Size determined by expected velocities.
- Wire screening, 0.5 to 1 in. heavy gauge, galvanized mesh.
- Backhoe or trencher.

Log Drop or Board Dam

- Two 6 to 12 in. diameter logs long enough to span the stream with a surplus of 8 to 12 ft. so the logs can be embedded in the streambank.
- Boards 2 in. thick.
- Spikes or heavy nails.
- Stone riprap, sized to withstand expected maximum stream velocities.
- Backhoe or trencher.

Rock Check Dam and Split Rock Check Dam

- For streams up to 20 feet wide, the main rocks should weigh about 800 to 1000 pounds. Streams up to 100 feet wide require rock weighing greater than 2000 pounds.
- Backhoe or trencher.

Construction

Jack Dam (Figure 5-20)

a. The upstream log should be placed into the stream bed to a depth at least the full diameter of the log.

b. The double flooring should be placed from bank to bank with the top layer covering the joints in the bottom layer. A sheet of plastic is recommended to be positioned between the two layers to increase the longevity of the dam.

c. There should be a minimum of 1.5 ft. of bank above the top of the wing walls.

d. The opening between the wing walls should be sufficient to provide a normal flow of several inches of water across the dam. A general rule to follow is to measure the narrowest width of the stream in the area and size the wing wall opening to match it.

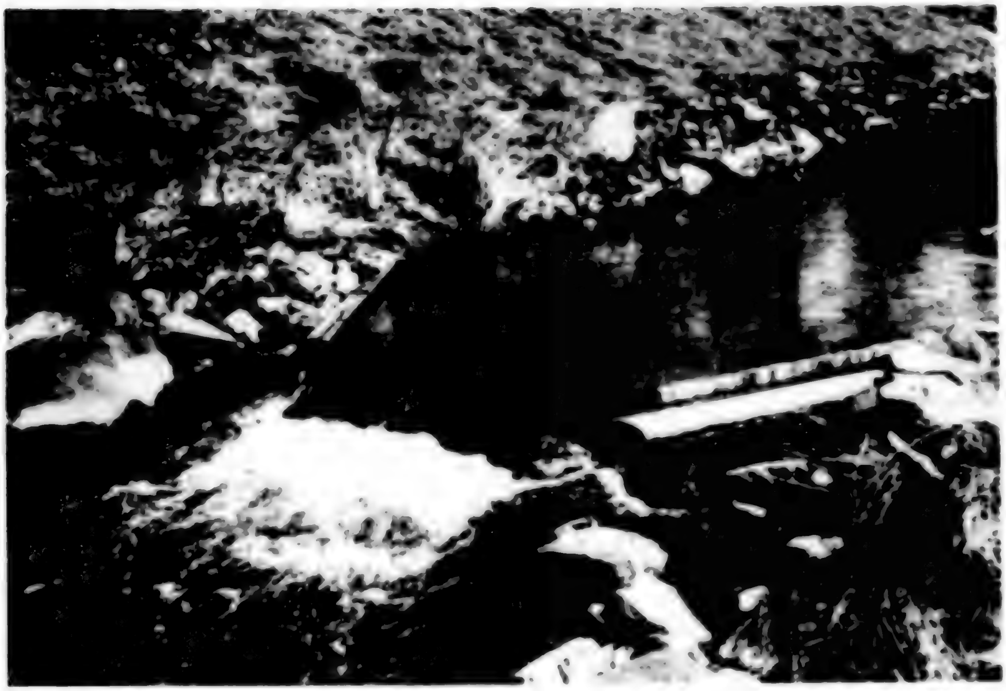

Figure 5-16. Jack dam used in a small, relocated stream in Pennsylvania.

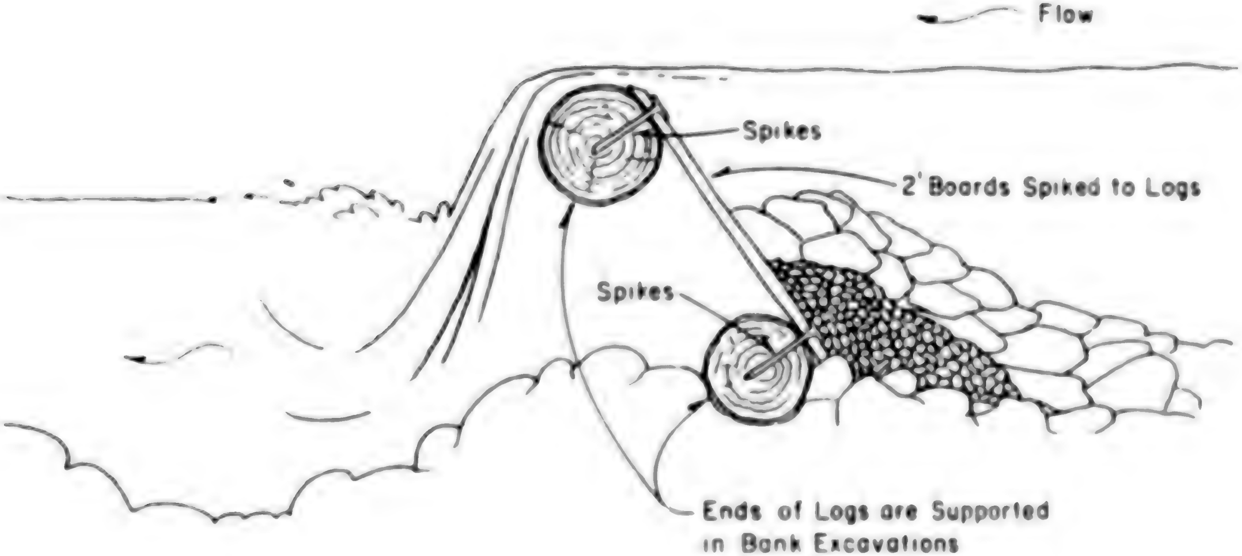

Figure 5-17. Log drop dam (Adapted from U.S. Forest Service, 1969).

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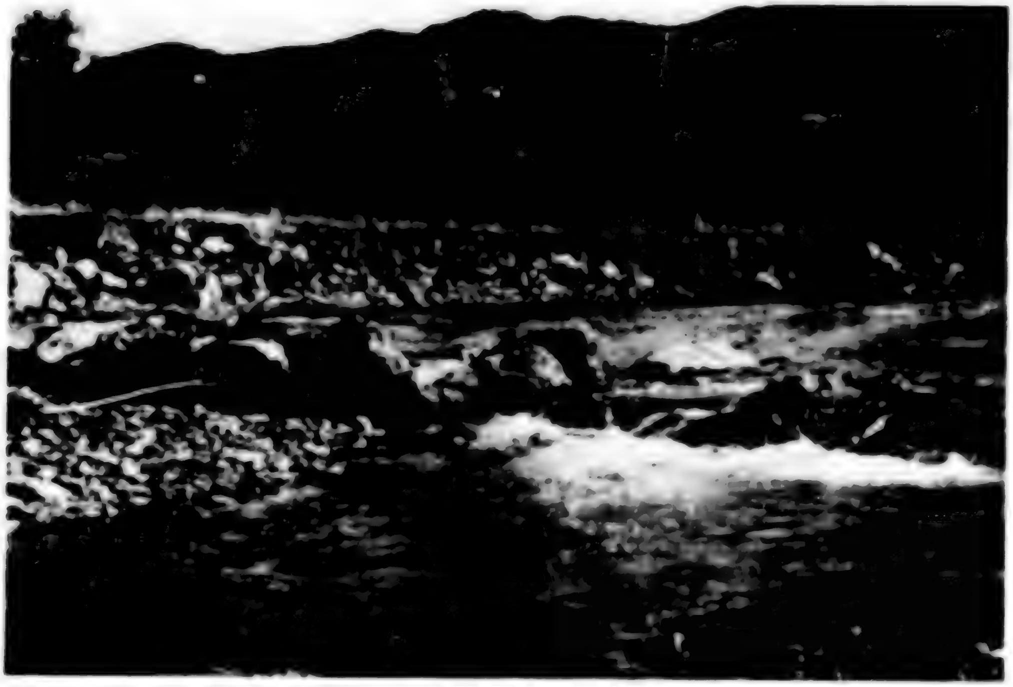
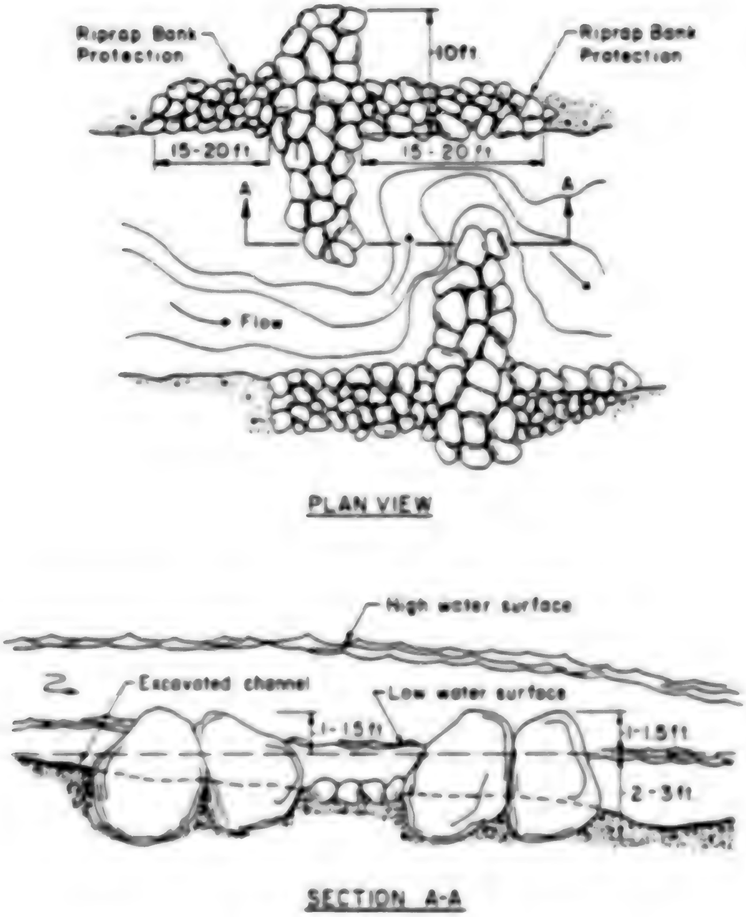


Figure 5-18. Rock check dam in a Colorado stream.



PLAN VIEW

SECTION A-A

Figure 5-19. Split rock check dam (Adapted from Federal Highway Administration, 1979).

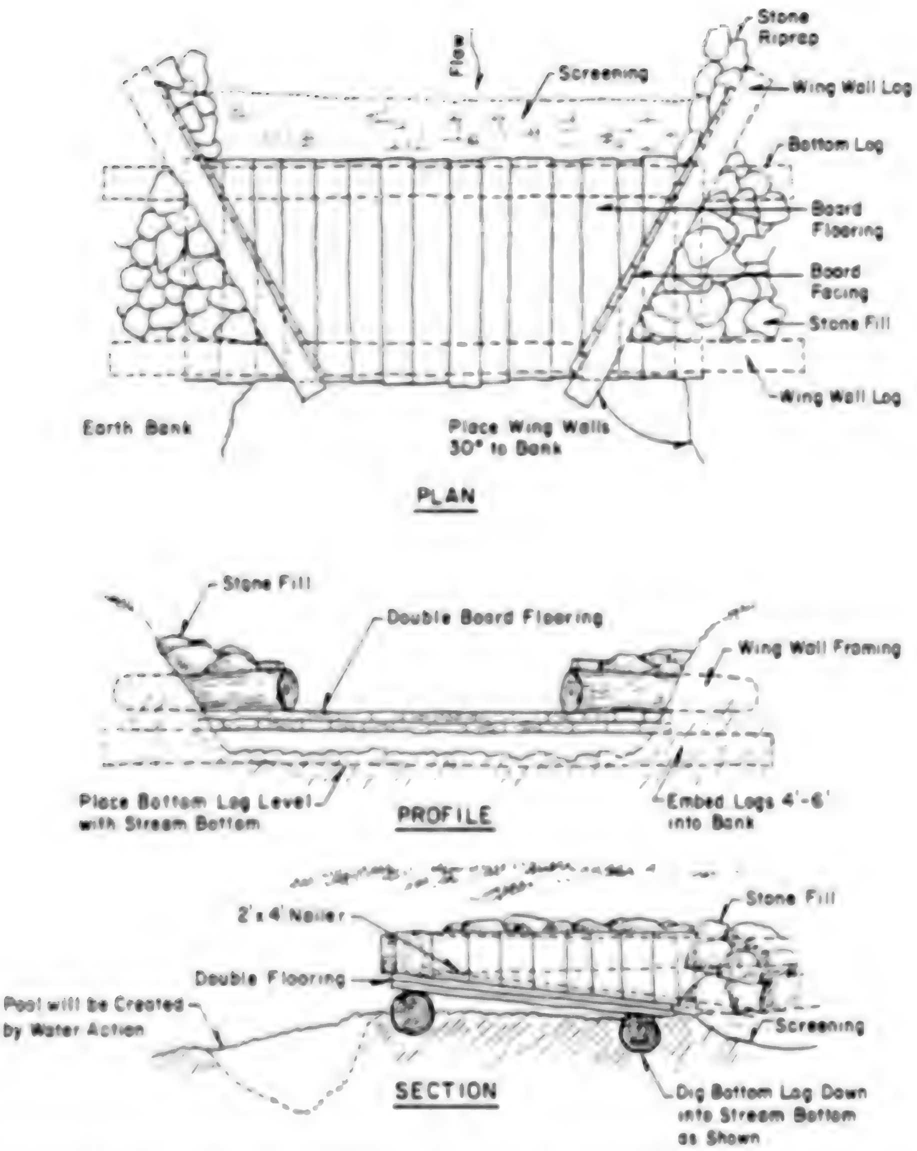


Figure 5-20. Jack dam construction details (Adapated from Pennsylvania Fish Commission, 1980).

Log Drop or Board Dam (Figure 5-17)

a. Place the logs perpendicular to the streamflow, either on top of each other or staggered.

b. Embed these logs 4 to 6 ft. into the banks on both sides of the stream.

c. Nail the planks to the logs. Planks can either be driven into the stream bed or cut to match the uneveness of the bottom. Planks should not extend above the upper log but should extend into the excavation for a short distance. Planks should be soaked in water before using to reduce buckling and expansion when submersed.

d. Place gravel at the base of the planks and cover gravel with larger rocks.

e. Backfill excavation and compact.

f. Place stone riprap on the banks where the logs are buried to prevent erosion.

g. To increase scouring, a third log can be placed on top of the structure. This log should be suspended several inches above normal flows so that water will cascade over it during high discharge periods. This log must be securely anchored into the banks because it is subject to flood flows without any additional support. A disadvantage of this additional log is that debris may be trapped between it and the dam, thereby impounding more water than intended.

Split Rock Check Dam or Rock Check Dam (Figures 5-19 and 5-21)

a. Embed rocks into channel bottom at least 2 feet and extend rock dams into banks 6 to 10 feet.

b. Provide riprap bank protection both upstream and downstream of the junction of the dam and bank.

Maintenance

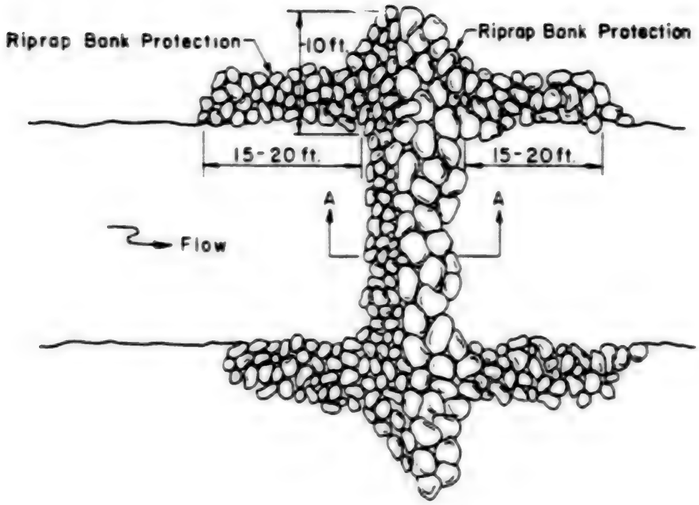
All types of dams should be checked for structural damage after high discharge periods. Log jams and trapped debris should be periodically cleared. Downstream and adjacent streambanks should be examined to determine if an unreasonable amount of erosion is occurring. If the downstream impacts are severe, the dams should be modified accordingly or removed.

Evaluation

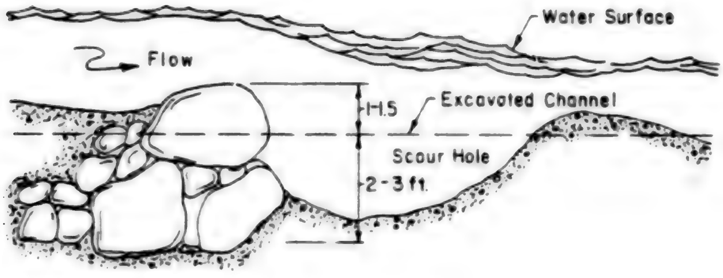
It is reported that the use of log drop structures increases fish habitat by producing the desired scouring downstream of the devices (Brusven, et al. 1974). However, these structures should not be used unless the stream has a gradient sufficient to minimize pool formation behind them (Pennsylvania Fish Commission, 1980). Board dams are recommended for streams with rocky substrate so that the bank support is adequate to prevent the dam from washing out (U.S. Forest Service, 1969). Such spans should be limited to a short stream segment.

Plunge pools below dams provide excellent fish habitat and the downstream gravel bar which often forms below the dams makes an ideal spawning bed (Federal Highway Administration, 1979). To prevent blockage of adult trout movement, the dam should not have a vertical jump in excess of 1 to 1.5 feet and the downstream pool should have a minimum depth of two feet. This minimum pool depth may need to be excavated during installation.

When considering the use of cross-channel structures for relocated streams, it may be better to design the channel with varying slopes rather than to construct a dam to achieve pools and riffles. The dams appear to have a high potential to cause more damage to aquatic habitat and to change the hydraulic capacity of the stream than to provide benefits. However, if properly designed, installed and maintained in streams lacking sufficient cover and shelter for fish, these low level devices can be a viable alternative for producing scour.



PLAN VIEW



SECTION A-A

Figure 5-21. Rock check dam construction details (Adapted from Federal Highway Administration, 1979).

As with all stream structures, the cost is dependent on the size of the stream and the availability of materials and equipment onsite. Log drop structures constructed on a stream 10 to 20 ft. wide required an estimated 20 man-hours to complete (Brusven, et al. 1974). Access by heavy equipment, such as a backhoe for bank excavation, facilitates dam construction.

5.1.4 Instream Cover Devices

Purpose

Instream cover devices provide cover and shelter for fish. Small pools that form behind such devices provide resting and hiding places for fish and a variety of other aquatic organisms.

Description

Cover structures are simple, easily installed devices, randomly placed in streams to provide fish with secluded areas and they are especially useful in artificial channels that have little or no overhanging vegetation or stream debris. Three devices including random boulders, half-logs, and elevated boulder structure are presented in this section. All serve to increase the diversity of available habitat for aquatic life.

Equipment and Materials

Random Boulder Placement Requires:

- Large boulders, ranging from 4 to 8 feet in diameter, based on expected stream velocities and availability.
- Front-end loader or other suitable equipment for movement of large boulders.

Half-log Device Requires:

- Half-log or sturdy wood slab, 4 to 8 ft. long by 4 to 6 in. thick by 1 ft. wide.
- Two wooden spacers - short log sections.
- No. 4 to No. 6 steel reinforcing rod (0.5 to 0.75 in. in diameter) for anchoring logs.

Elevated Boulder Structure Requires:

- Two 8 ft. sections of 8 to 12 in. diameter logs.
- Two-inch thick wood planking.
- No. 4 to No. 6 steel reinforcing rods (0.5 to 0.75 in. in diameter) to anchor logs.
- Heavy stone fill, generally 1 to 2 ft. in diameter.

Construction

Boulder Placement (Figure 5-22 and 5-23)

a. Position boulders in random fashion in the main channel so they will be effective during low flows.

b. Oblong boulders should be placed with the long axis at right angles to the streambank.

c. Avoid deflecting currents into soft banks and do not place boulders in narrow channels where they may restrict flows.

d. The maximum number of boulders should not exceed one per 300 square ft. of channel (U.S. Forest Service, 1969).

Half-log Device (Figure 5-24)

a. Position the half-log parallel to the stream current and over the two spacers placed on the stream bottom. The upstream end should be slightly lower than the downstream end.

b. Drive the reinforcing rod through holes drilled in both the half-log and spacers. The rod should extend several feet into the stream bottom.

Figure 5-22. Use of random boulders in a stream in Colorado.

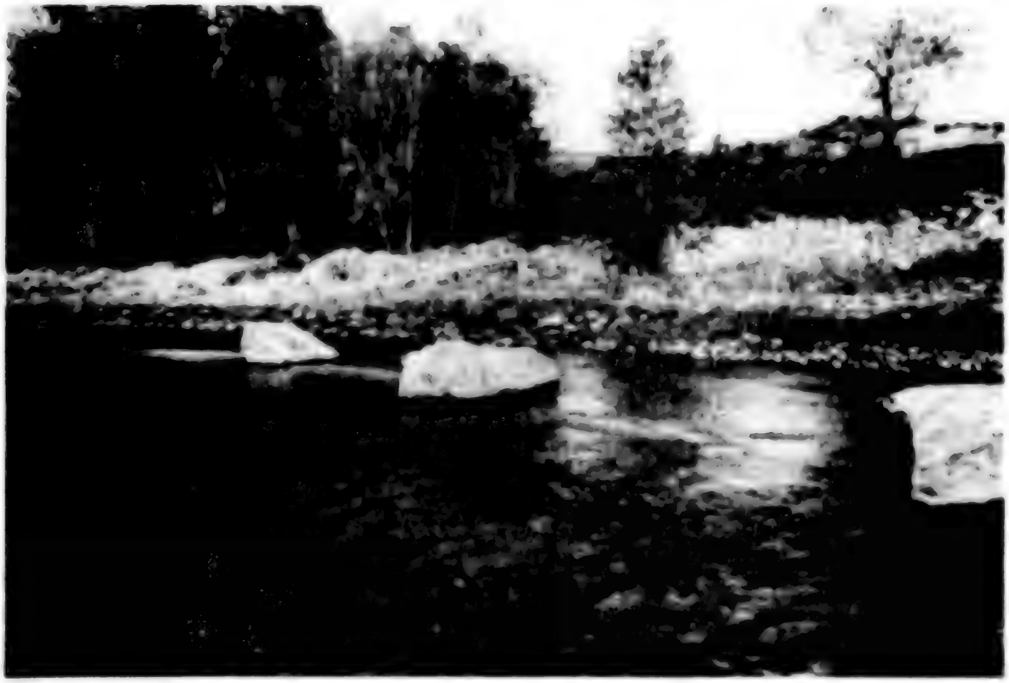


Figure 5-23. Random boulder placement in a stream improvement project in Colorado.

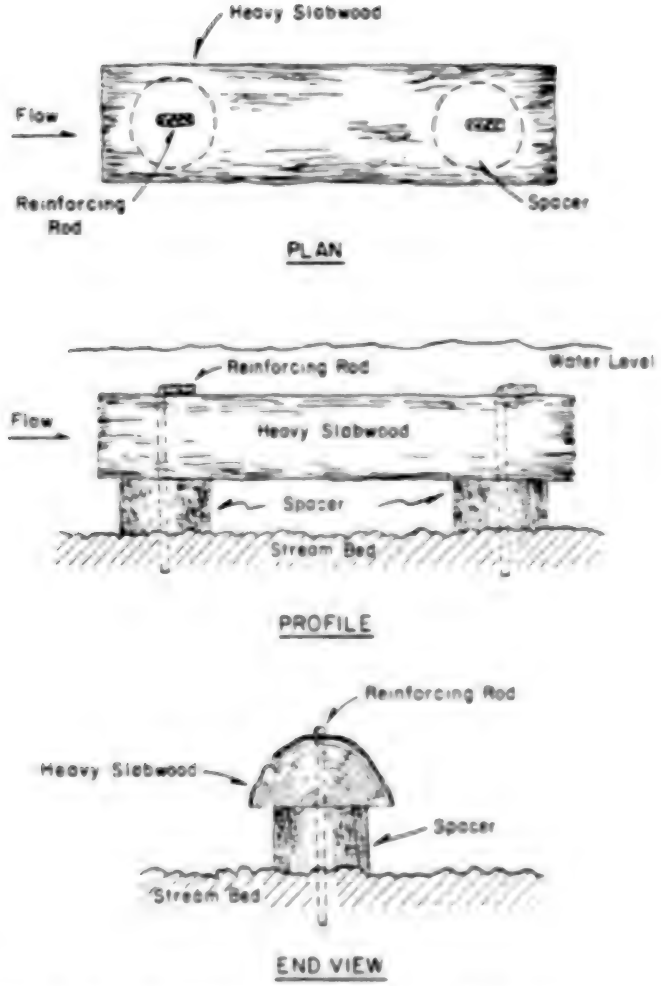


Figure 5-24. Half-log device (Adapted from Pennsylvania Fish Commission, 1980).

c. Bend the top of the rods back so that they point downstream.

Elevated Boulder Structure (Figure 5-25)

a. Place logs on stream bed, parallel to stream flow. Secure with steel rods.

b. Nail planks across the logs to create a floor for the stone fill.

c. Frame outer edges of the structure with additional planks to hold stone in place.

d. Fill to top with heavy stone.

Maintenance

All of these devices should be relatively maintenance-free. The elevated boulder structure and half-logs should be examined after ice-out in the spring and after flood events. Stone should be replaced as needed.

Evaluation

Cover structures effectively add cover and shelter to a stream, thereby providing improved fish habitat. Labor and material requirements are minimal for most structures. Large diameter boulders should be placed so that their effectiveness is not lost by burying themselves in unstable substrate (Bulkley, et al. 1976). Most literature reports that fish were observed near cover devices installed on streams but no quantitative documentation on the increase of the stream's capability to support fish populations was found during the information review of instream cover devices. The use of random boulders may be the most cost effective stream improvement technique available. Boulder placement requires little or no expertise and it is easily accomplished using front-end loaders. Random boulders also improve the natural appearance of the stream.

5.1.5 Artificial Riffles and Pools

Purpose

The purpose of artificial riffles and pools is to vary the gradient in the stream, thus providing habitat diversity.

Description

This approach imitates the natural stream characteristics of alternating shallow, rapidly-moving water with slower, deeper sections. It is generally applied to a channel that has uniform gradient and may consist of both pool excavation and raising the channel bottom.

Equipment and Materials

- Excavation equipment such as a backhoe, and front-end loader.
- Rock sized, as a "rule of thumb," by imitating rock dimensions found in upstream and downstream natural riffle areas (see Figure 5-26).

Construction

a. Construction consists of alternating excavation of the channel bottom and placement of rock in the channel. It is estimated that in a natural stream, pools and riffles alternate every five to seven channel widths (Leopold, et al. 1964).

Maintenance

Continued maintenance will probably be required to keep riffles in place. Pools will eventually require re-defining as they silt in.

Evaluation

A channelized section on the Olentangy River in Ohio was studied in which a series of artificial riffle-pool sequences was constructed (Griswold, et al. 1978). Five equally spaced riffles, each 20 feet long were constructed of boulders over earthen fill. The pools below each riffle were 820 feet long with a maximum depth of 8.2 feet at mean discharge. A comparison of this channelized reach with unaltered sections on the same river showed that the artificial riffle-pool areas were effective in providing standing crops of desirable fish ap-

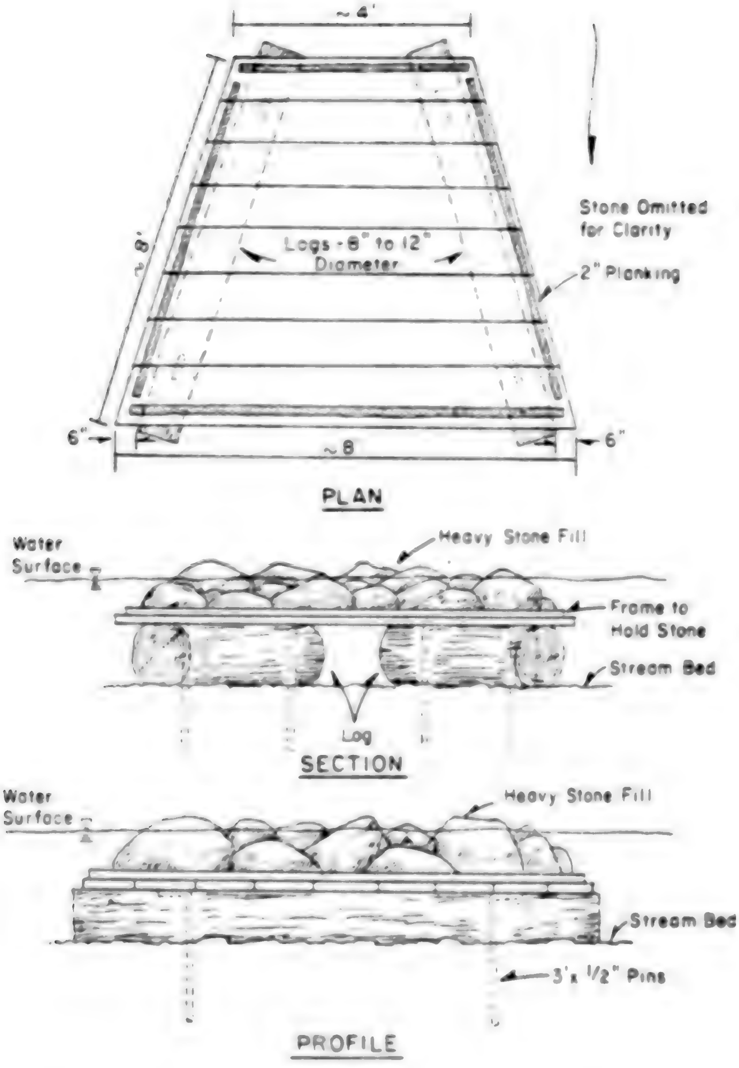


Figure 5-25. Elevated boulder structure (Adapted from Pennsylvania Fish Commission, 1980).

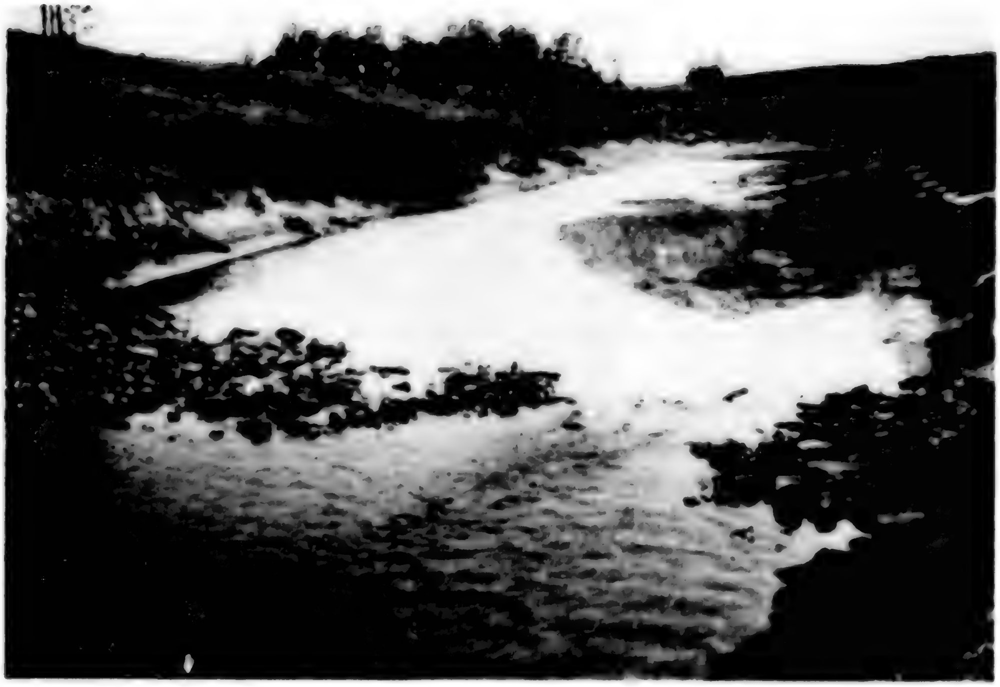


Figure 5-26. Artificial riffle created by dumped rock in an Illinois stream.

proximating those in the unaltered reaches of the stream.

The primary problem with this method is that unless it takes into account the natural stream processes such as scouring, sediment transport and meandering, the channel bed configuration will not remain as intended. Because natural actions are difficult to predict with any confidence, the creation of artificial riffles and pools must be considered a trial and error proposition. Riffle areas created by dumped rock are particularly vulnerable to movement during high discharge events. However, even when artificial riffles are "blown out" during floods, they may still contribute to the benefit of aquatic organisms by providing rock substrate for shelter or as an attachment surface.

5.2 - FISH BYPASS STRUCTURES

Purpose

Fish bypass structures, also termed fishways are devices to assist fish movement over or around stream obstructions such as dams or shallow rapids. Blockage of fish movement can reduce spawning and rearing capabilities of the stream, thereby eliminating natural populations of a particular species by limiting access to suitable areas for reproduction. This situation may occur during mining operations where an in-stream impoundment has been built to serve as a water supply or for sediment control or, in the case of a relocated stream when stream length has been shortened and drop structures must be employed to match gradients.

Description

Several types of fishways are available for use on streams. These devices include pool-and-weir, pool and orifice, notched logs, Denil-type and vertical slot or deep-baffled fishways.

The pool-and-weir arrangement consists of a series of boxes created by vertical partitions (weirs) set in a chute (Figure 5-27). The water flows over the weirs creating a staircase effect. They must have sufficient depth to eliminate excessive turbulence and must be long enough to reduce strong currents working against the next weir.

The pool-and-orifice type is similar to the pool-and-weir, with the addition of openings located in the downstream walls of each pool (Figure 5-28). These devices allow passage both over and through the weirs, making them effective under more variable stream flow conditions.

Notched logs are small log dams with a low flow notch to consolidate stream flows (Figure 5-29) and are used to create a step effect. These devices are suited to small, steep gradient streams that would normally be too shallow for fish passage. An added benefit to the use of these structures is that under proper conditions (limited silt input upstream), they will trap gravel behind them, producing potential spawning areas.

Denil-type fishways are narrow chutes or flumes with closely spaced baffles attached to the bottom and sides to reduce water velocities (Figure 5-30). They can be used in steep gradient situations and can be operated without adjustment as long as there is water passing over the baffles. They are best suited to streams flowing under 1000 cubic feet per second and where water level fluctuations do not exceed 3 feet (U.S. Forest Service, 1969). A portable modification, the Alaskan Steeppass, has been developed using prefabricated aluminum and can be used to assess the potential of a site for fishways prior to the construction of more costly structures (Kerr Wood Leidal Associates, Ltd. and D. B. Lister and Associates, Ltd. 1980).

The vertical slot fishway (Figure 5-31) consists of a series of baffles extending the entire heighth of the chute, creating pools behind the baffles in a manner similar to the pool-and-weir. The advantage of this is that it operates under a wide range of flow conditions. However, the volume

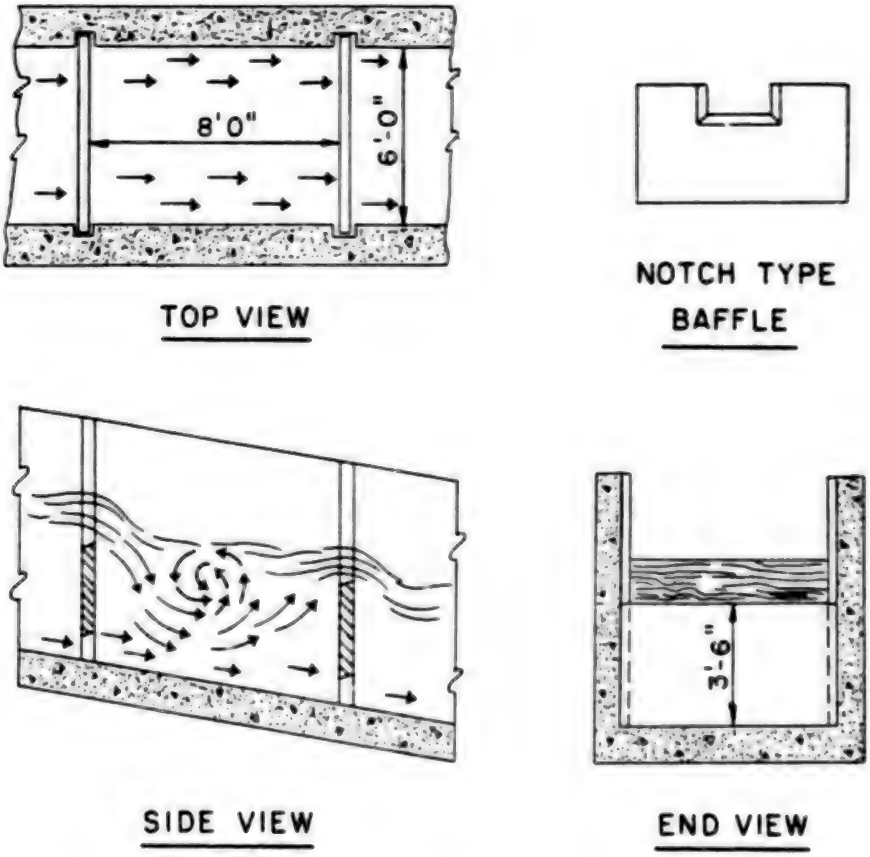


Figure 5-27. Pool-and-weir fishway (From W. Harry Everhart and William D. Youngs: Principles of Fishery Science, Second Edition. Copyright © 1981 by W. Harry Everhart and William D. Youngs. Used by permission of the publisher, Cornell University Press.).

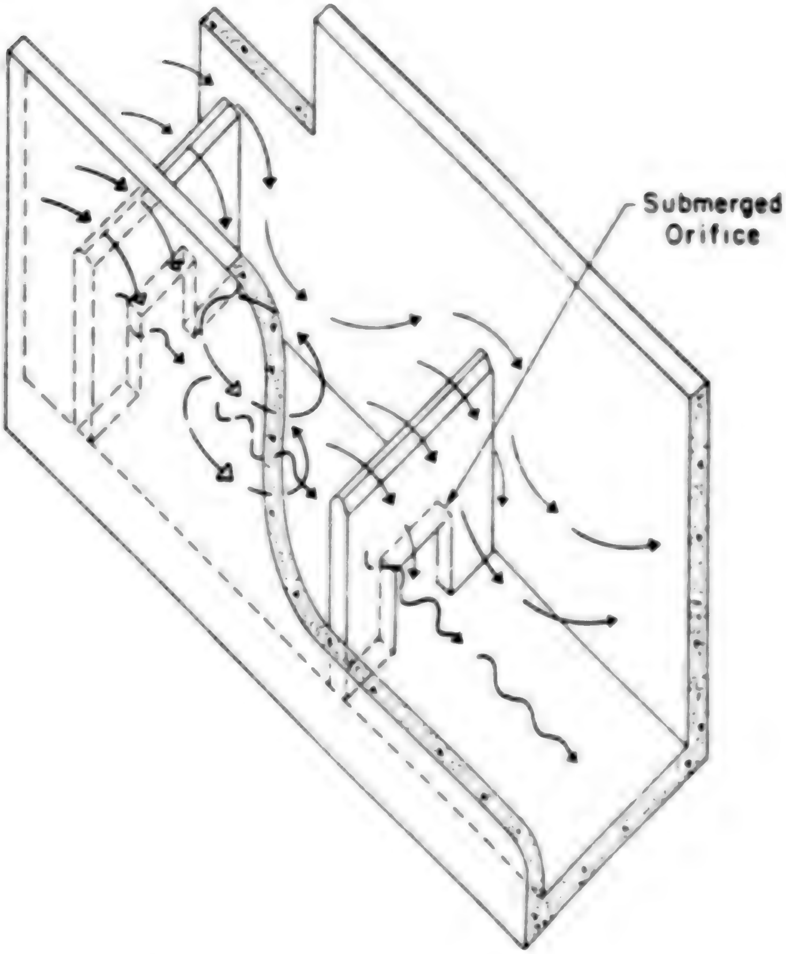
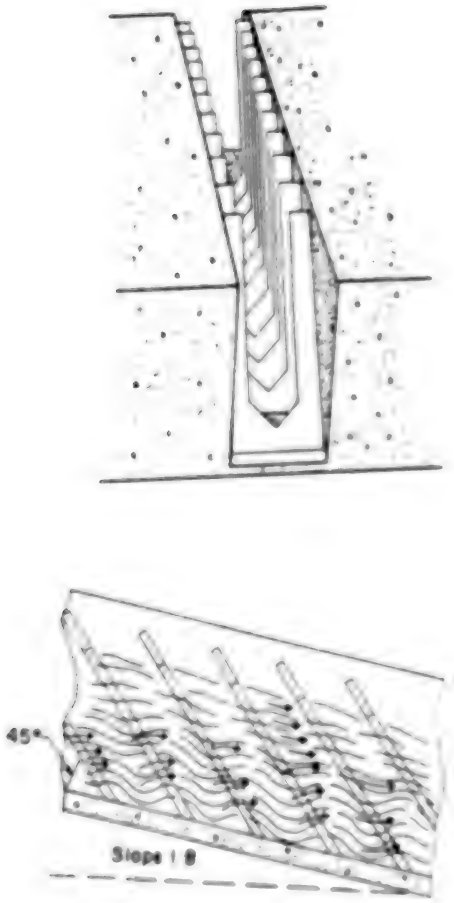


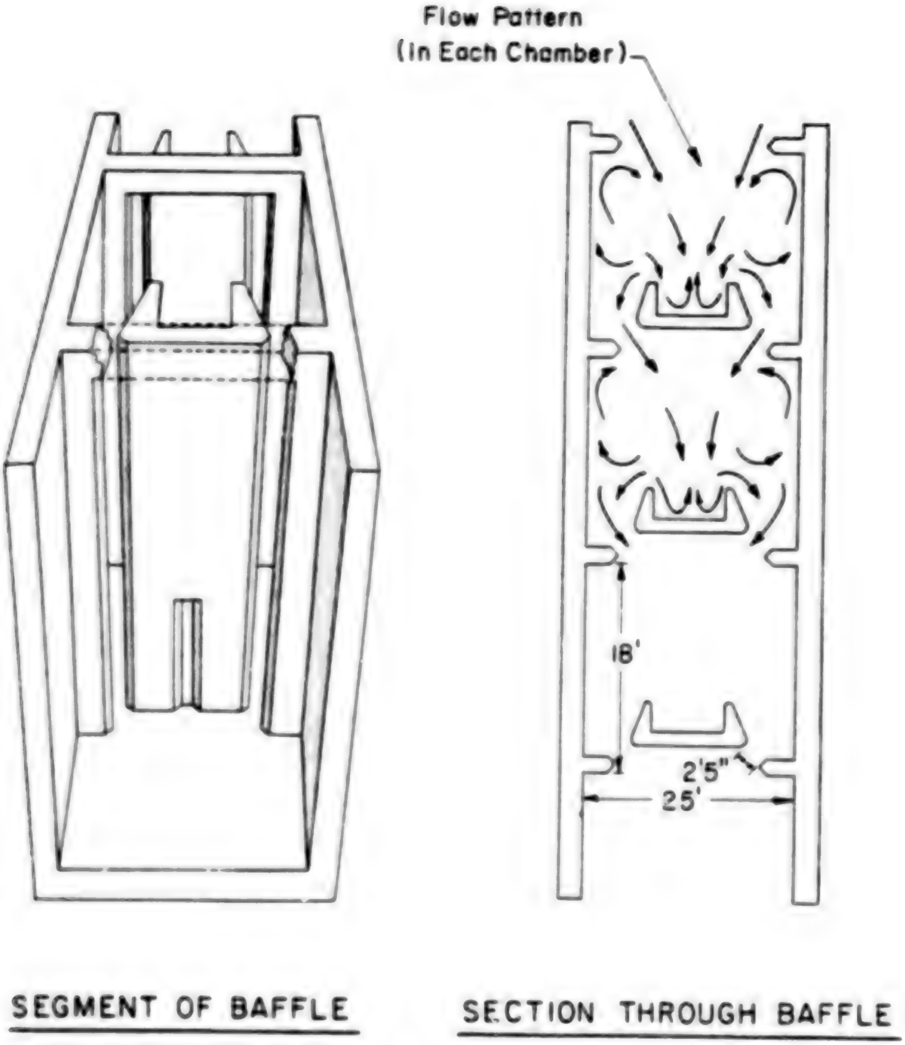
Figure 5-28. Pool-and-orifice fishway (Adapted from Kerr Wood Leidal and Assocaites, Ltd. and D. B. Lister and Associates, Ltd., 1980).

Figure 5-29. Notched log arrangement for facilitating upstream fish migration in Utah.



SIDE VIEW

Figure 5-30. Denil-type fishway (From W. Harry Everhart and William D. Youngs: Principles of Fishery Science, Second Edition. Copyright © 1981 by W. Harry Everhart and William D. Youngs. Used by permission of the publisher, Cornell University Press.).



SEGMENT OF BAFFLE

SECTION THROUGH BAFFLE

Figure 5-31. Vertical slot or deep baffled fishway (Adapted from Nelson, et al., 1978).

of water necessary to keep sufficient depths for fish passage confine its use to larger streams and weirs.

General Fishway Design Considerations

The selection of a particular fishway should be based on site-specific fish passage problems. Some general requirements presented by Everhart, et al. (1975) are:

- It should be suitable and passable for all migrating species in the area.
- It should operate at all water levels above and below the obstruction.
- It should operate at all volumes of stream flow.
- Fish should ascend the fishway without injury or extreme exertion.
- Fish must find the entrance, enter quickly and pass through the fishway without delay.

Several other guidelines and considerations of fishway design features should include:

a. Entrance - This is the most critical design and positioning characteristic. Velocities of the water passing through the fishway must be controlled such that they are attractive to the fish. In general this means that at the entrance the water velocity should exceed 3 feet per second but not exceed 5 to 8 feet per second (U.S. Forest Service, 1969; Everhart, et al. 1975). The location should be near or in the main current and as close to the obstruction as possible.

b. Exit - The exit or upstream end of the fishway should be fitted with a trash rack or other device to prevent accumulation of debris in the fishway and should end far enough upstream so that the fish exit into a nonturbulent pool.

c. Depth and Gradient - The minimum flow depth in the fishway should be 3 feet. The maximum drop between pools should be 1 foot. Gradients should be maintained at a steepness of 8H:1V (Horizontal to Vertical ratio) or less.

d. Resting Pools - It is recommended that resting pools be provided for every 10 feet of vertical change (U.S. Forest Service, 1969). The resting pools should have a current velocity of 1 foot per second or less.

Specific Fishway Design Considerations

Due to the specialized and site-specific nature of fishways, the listing of equipment and materials requirements construction specifications and maintenance are not appropriate. Instead, design considerations for the three most basic types: pool-and-weir, pool-and-orifice and the notched log fishways are presented.

a. Pool-and-Weir Design

Pool-and-weir design should include provisions to dissipate the energy from water passing over one weir before it reaches the next lower level. This is accomplished by providing pools of sufficient size. The following formulas account for this, based on the crest differential (the heighth difference between two successive weir crests):

Pool width = 2.5 x crest differential
Pool length = 10 x crest differential
Pool depth = 3 x crest differential

Also, the notch in each weir should be cut to a depth that is at about the same elevation as the succeeding weir crest.

b. Pool-and-Orifice Design

The orifices should normally be sized to provide an adequate flow over the weirs in addition to a flow through the orifice (Kerr Wood Leidal Associates, Ltd. and D. B. Lister and Associates, Ltd. 1980). The orifices should provide ample visual as well as physical clearances with a minimum width of greater than 10 inches. A 10-inch x 12-inch port is adequate for weirs 30 inches wide and 30 to 36 inches high (U.S. Forest Service, 1969).

c. Notched Log Structure (Figure 5-32)

The log(s) must be embedded at least 3 to 4 feet into each bank. The log may be pinned to the stream bed using reinforcing rods placed through holes drilled into the log or the channel bottom may be excavated and the log placed in the trench. The top of the log should not extend more than 1 foot above the stream bed so that fish can freely move within the stream. Both upstream and downstream banks should be protected with riprap at the point where the log intersects the bank.

Evaluation

The stream fishery's resource potential must justify installation of fish bypass structures. All of the structures require periodic maintenance and repair because they are vulnerable to debris accumulation. Improper design and/or installation can be detrimental to fish passage. The Forest Service recommends use of the pool-and-weir type because it is the "safest" (i.e. because even if they are not designed or installed properly, they will still function) (U.S. Forest Service, 1969). Fishways can be constructed in rock which can substantially reduce costs and improve their appearance (Kerr Wood Leidal Associates, Ltd. and D. B. Lister and Associates, Ltd. 1980). One research team observed four pool-and-orifice fishways and found two to be successful (Nelson, et al. 1978). The other two that were unsuccessful were judged to have poor entrances.

5.3 - STREAMBED IMPROVEMENTS - MECHANICAL REHABILITATION

Purpose

The purpose of improving conditions in the stream bed, specifically the substrate, is to enhance fish reproduction and provide stable bed materials conducive to the development of a diverse aquatic community.

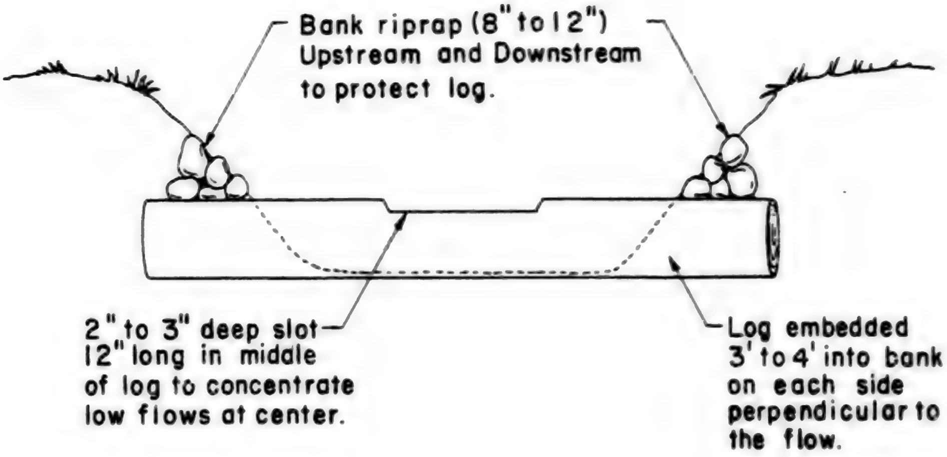
Description

Many species of fish, and in particular salmonids such as trout and salmon, require clean, gravelly areas in which to spawn. A literature review concerning aquatic invertebrates and substrate composition found that heavily silted streams were generally less productive and contained fewer species than clean, unsilted streams (Luedtke, et al. 1976). One of the major detrimental effects of channelization and relocation projects is the resulting changes in substrate (see Chapter 3). Thus, to enhance the recovery of altered streams, various methods have been implemented to re-establish or modify stream bottom conditions so that it presents a more favorable environment for aquatic invertebrates and fish spawning areas. These procedures include lining the channel bottom with rock (gravel and cobble); removing silt and fine-grained sediment through the use of current deflectors; or, mechanically rehabilitating the substrate. The advantages and disadvantages of introducing substrate have been discussed in Chapter 4, and current deflectors were previously addressed in this chapter. The following examines the use of mechanical means to recondition stream beds that have suffered from excessive sedimentation.

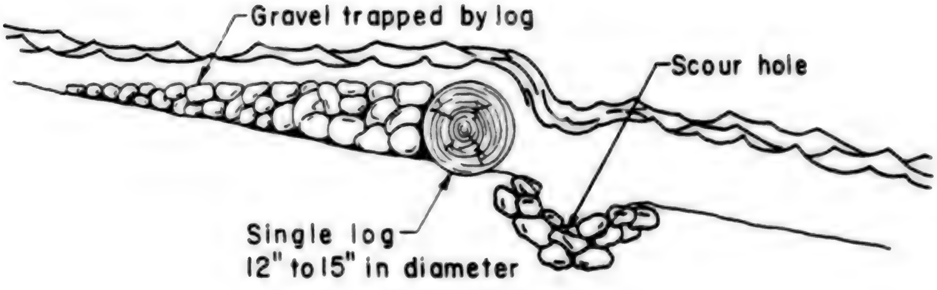
Discussion

Two types of methods for improving the existing conditions of a stream bed for spawning have been presented by the U.S. Forest Service (1969). Mechanical loosening involves raking, harrowing, disking, spading, plowing or even dozing the stream bottom to loosen gravels that have become cemented by silt or fine sand. This permits the flow of water between the gravel particles which is necessary in supplying oxygen and removing metabolic wastes for fish eggs.

The second method is utilizing a mechanical gravel cleaner. The machine pushes harrow-like teeth through silted gravel beds while high pressure jets of water are released into the water through the teeth. A device


Bank riprap (8" to 12") Upstream and Downstream to protect log.
2" to 3" deep slot 12" long in middle of log to concentrate low flows at center.
Log embedded 3' to 4' into bank on each side perpendicular to the flow.

CROSS SECTION



PROFILE

Figure 5-32. Notched log fishway construction details.

similar to a vacuum cleaner is positioned so that it is above the gravel bottom and sucks in the loosened sediment and discharges it in the form of slurry over the streambank.

A prototype gravel cleaner has been developed that utilizes water jets to penetrate the substrate to loosen silt (Mih and Bailey, 1981). Suction ports with screens to limit the size of sediment removed are employed. A cyclone separator is used to remove excess water and concentrate the pumped discharge. A schematic drawing of the major components of the machine is presented in Figure 5-33.

Evaluation

The original type gravel cleaner developed by the Forest Service is no longer in use because of numerous mechanical failures (Nelson, et al. 1978). The machine developed by Mih and Bailey is designed for a specific stream size (about 30 feet wide) and a specific substrate. This machine operated at water depths of up to 36 inches, a speed of 0.3 feet per second and cleaned the gravel to a depth ranging from 6 to 12 inches. The Washington State Department of Fisheries is presently testing the machine under varying conditions.

Mechanical methods for restoration of stream beds holds promise, but cannot be considered a practical alternative at present. It is also a temporary corrective measure, it does not address the more permanent solution of reducing sediment entry to the stream. It does, however, hold potential as a practice that has future application for streams that are no longer subjected to excessive siltation - a situation that can occur on reclaimed surface mine lands.

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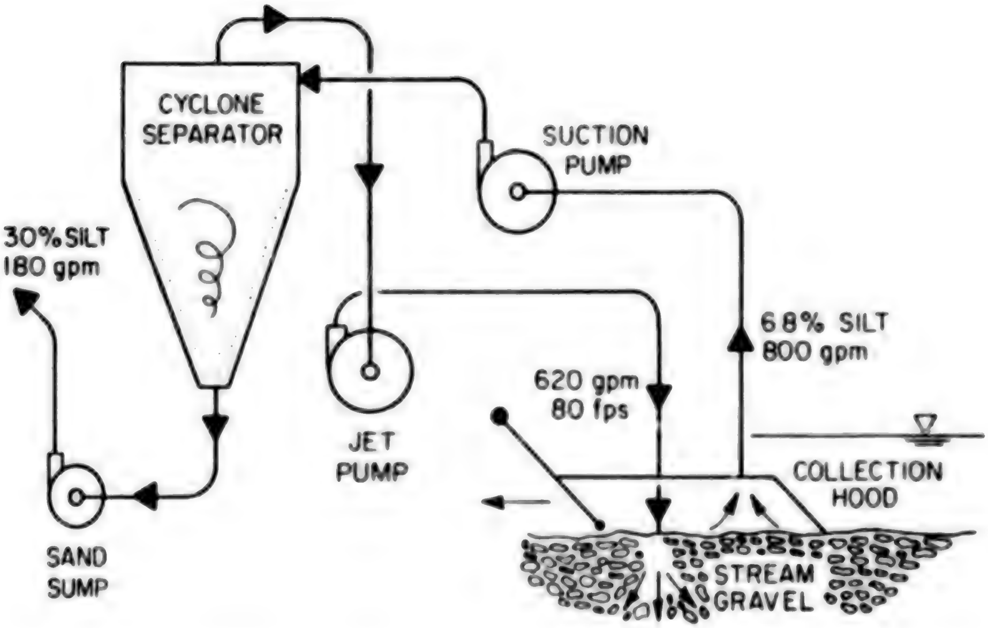

Figure 5-33. Schematic illustration of a mechanical gravel cleaner (Adapted from Mih and Bailey, 1981).

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APPENDIX A

HYPOTHETICAL CASE STUDIES

This appendix presents three hypothetical mining operations, each in a different setting, that require stream alterations. The purpose of this appendix is to suggest how techniques presented in this document can be applied to typical situations that arise when stream modifications are being considered or occur at coal mine sites.

Several assumptions were made in the preparation of these mining scenarios. Two general assumptions are that 1) the mine operator has already developed lines of communication with the appropriate agencies such that a working relationship has been established, and 2) each situation presented herein has been approached in an interdisciplinary manner (i.e. the operator has assembled a team whose expertise includes ground and surface water hydrology, hydraulics, geotechnical engineering and aquatic ecology). Specific assumptions include:

1. The case studies have been presented without addressing any of the state or federal surface mining regulations.
2. Other state and federal permits such as stream encroachment, floodplain construction, or dredge and fill (Section 404) may be required to implement some techniques. It is assumed that these permits have been identified and approval to carry out the proposed stream alterations has been granted by the appropriate agency(ies).

CASE STUDY NO. 1 - EASTERN COAL PROVINCE

Setting

Contour mining is one of the common methods for coal extraction in the Eastern Coal Province, which is characterized by steep slopes and numerous steep gradient first-order intermittent streams. Figure A-1 shows the drainage pattern where a section of a proposed contour surface mine is to be located. Figure A-2 shows the proposed mining plan. The plan is to mine through the two intermittent streams shown, but to avoid mining of Stream X. The premining assessment (Section 4.1.2) revealed that Stream Y is a high quality stream with a native brook trout population. The trout presently use Stream X as a spawning and nursery area, thus dictating that fish migration not be blocked on this stream.

Problem Identification

For this case, three potential alterations are singled out for discussion. First, the two intermittent streams must be diverted before reaching the highwall to keep water from draining into the pit area. Secondly, the haul road construction will require that the perennial stream (Stream X) be culverted under the roadway. The final problem is that as a result of placing the culvert on Stream X, the grade of the stream reach immediately upstream from the culvert must be increased to install a properly functioning culvert. Each of these three alterations is addressed as follows.

Diversion of the Intermittent Streams

Based on the reclamation plan for the mine, it was determined that the diversions will be temporary; thus, the streams will be returned to their approximate original locations after mining has been completed. Also, as a result of the mine site investigation and discussions with the regulatory agency, it was determined that these two streams have limited biological potential and therefore, the major concern is that the diversions are constructed so that the banks and channel beds are stable, and that they have sufficient capacity to handle the design discharges.

The steps outlined in Chapter 4 were followed in the planning of these diversions. Assuming that the need to divert and the baseline assessment (Sections 4.1.1 and 4.1.2) was already completed, the next step was to select the preliminary corridor for the diversion routes. In the Eastern Coal Province, the route (and alignment) is often constrained by the steep topography and in this particular situation, the only viable alternative was to divert both streams to the perennial stream (Stream X) (Figure A-3). The methodology for determining the design discharge was set by the regulatory authority, who specified the procedure to be followed and the design event to be used. Then, based on the slope of the route selected, estimates of the roughness of the channel (to get 'n') and the design discharge, the channel cross-sectional area was determined from Manning's Formula and the continuity equation (Sections 4.1.2 and 4.1.5). Due to its ease of construction, a V-shaped channel configuration was selected. Velocities in the channel were determined (from Manning's Formula) to select the appropriate channel liner. Due to the steepness of the terrain, velocities in excess of those recommended for vegetative linings were expected (see Table 4-2, Chapter 4) and thus a rock lining was chosen. The rock liner was not only capable of withstanding higher velocities but also reduced velocities due to its rough nature, and thereby added a factor of safety in the channel stability. Construction specifications were based on the design information. Included in the specifications were guidelines for bank stabilization utilizing seeding, mulching and fertilizer rates recommended by the local Soil Conservation Service. Finally, a rock chute was extended into Stream X (see Figure 4-16) where the diversion entered the main channel. This was constructed to protect the stream channel from erosion.

Haul Road Crossing

To select the most acceptable stream crossing, factors listed in Section 4.4 were followed. Based on relative costs, the small size of the stream, and the heavy equipment that would be crossing the stream, a culvert was selected as the best alternative. The next step was to determine the best type of culvert to use based on information included in Section 4.4.3. The key environmental consideration was to promote fish passage since this stream is used as a spawning ground. Thus, a structural plate arch (see Table 4-4) was selected. The advantage to this is that the natural stream bottom could be left intact. Calculations of the culvert hydraulics revealed that high velocities would occur during spring runoff periods. Therefore, as a fish enhancement technique, a resting pool was created downstream from the culvert using stone weirs (see Figure A-4) similar to the method shown in Figure 4-26.

Stream X Upstream From the Culvert

To maintain an acceptable approach to the culvert, the stream reach (Stream X) immediately upstream from the culvert entrance was reduced in gradient. This created a significant increase in the gradient in a subsequent upstream reach, which in turn presented a potential fish passage obstruction. Agency concerns regarding blockage of spawning fish meant that a fishway (see Section 5.2) be provided at this location so that suitable spawning habitat upstream would not be lost. The nature of the stream (narrow and steep) and the relatively few number of fish expected to spawn upstream from the culvert resulted in the selection of a notched log weir-type arrangement (Figure A-3). The notched logs were installed as shown in Figure 5-32 and were spaced such that fish would not have to negotiate a vertical increase of more than one foot at each log structure (Figure A-4).

Fish and Wildlife Benefits

The following benefits were gained by this approach:

- Stable diversions which lessen the impact of suspended solids to Stream X.
- Fish passage was enhanced through the haul road culvert by maintaining adequate stream depths and providing a resting area for fish.
- Improved access to upstream spawning and rearing areas was accomplished through the installation of an inexpensive fishway.

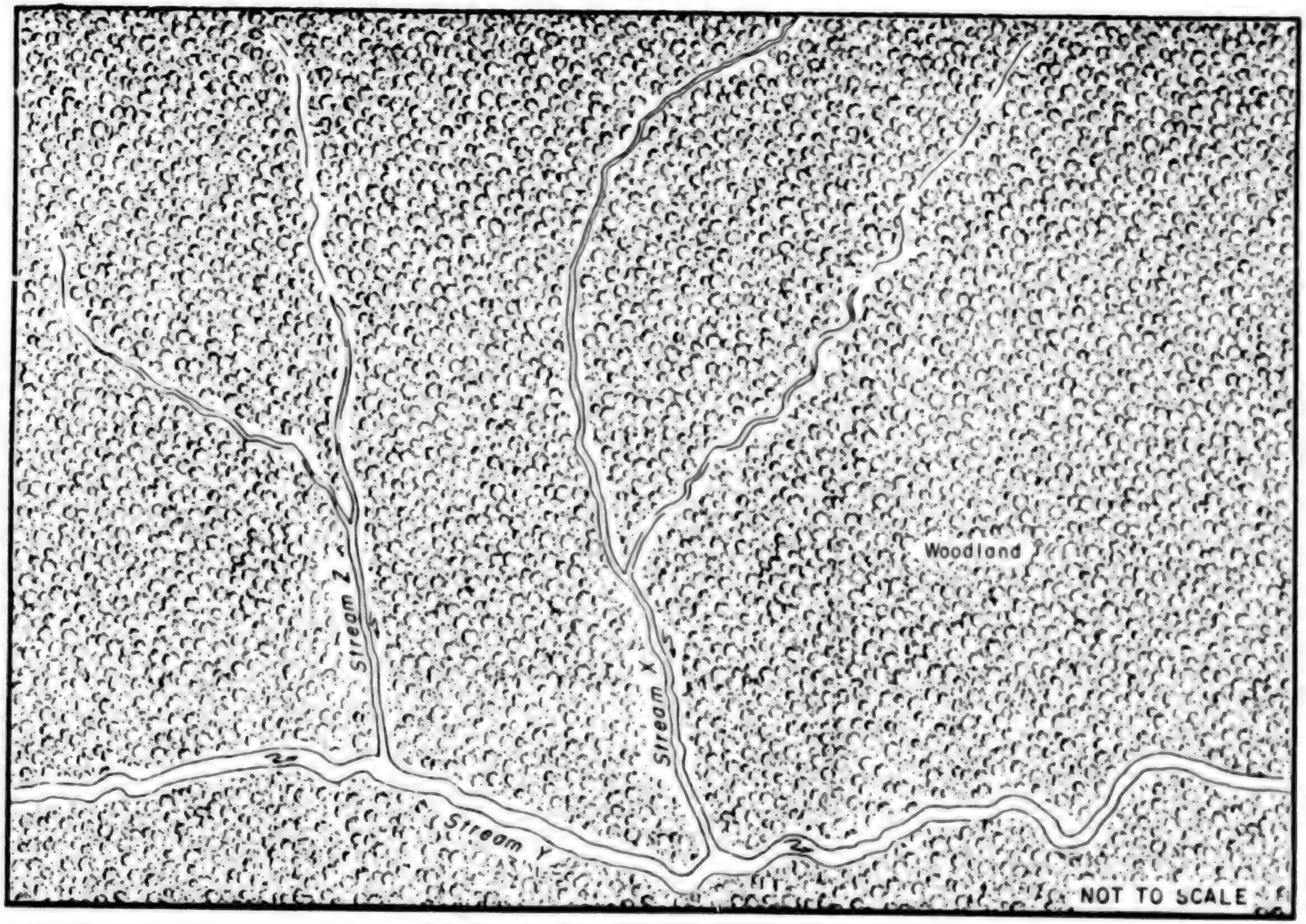

Figure A-1. Premining conditions.

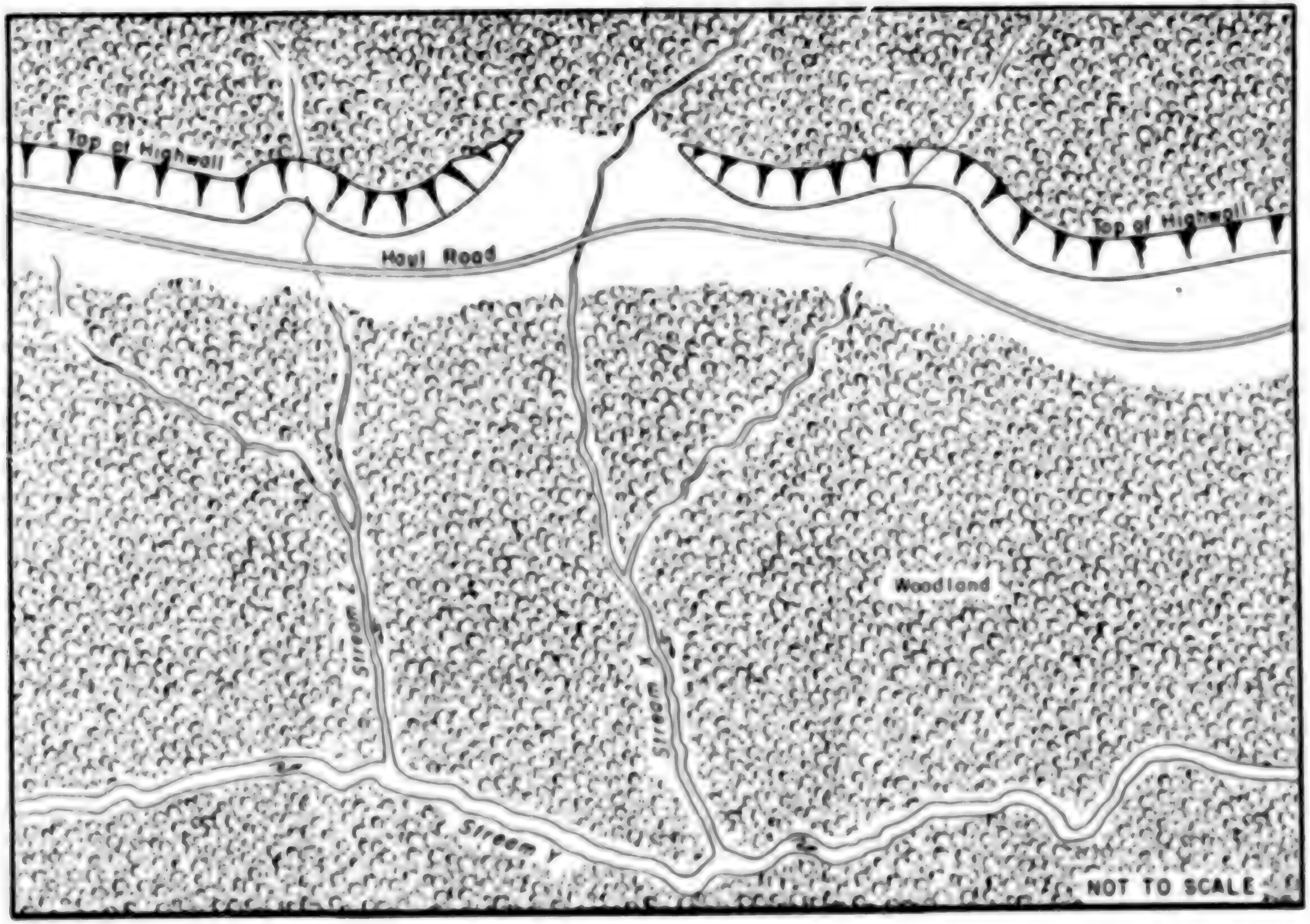

Figure A-2. Contour mining operation.

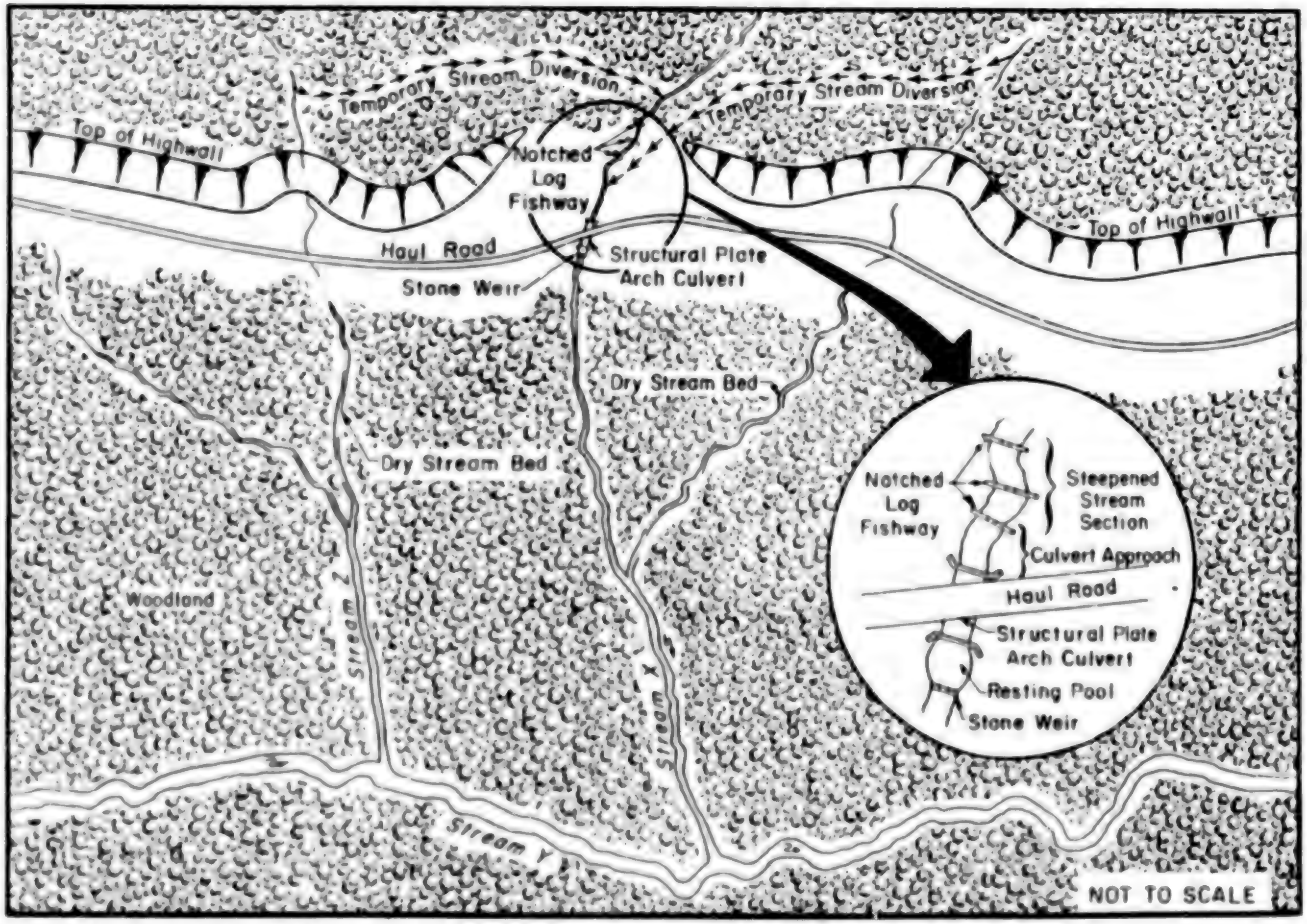

Figure A-3. Mining operation with stream enhancement structure in place.

Figure A-4. Notched log fishway.

CASE STUDY NO. 2 - INTERIOR COAL PROVINCE

The Interior Coal Province of the midwestern United States is represented by gently rolling topography, and agriculture is the dominant land use. The major streams are typically low gradient, perennial waterways that as a result of the intense agricultural development receive high sediment and nutrient loadings. Many of these streams have experienced channelization along at least some portion of their length as a flood control measure or to improve drainage from farmers' fields. The streambanks are composed primarily of fine sands and silts; are susceptible to erosion; and in many sections approach a near vertical slope. Vegetation, and not self-armoring (see Chapter 2) provides bank stability in these reaches.

For this example, an area mine utilizing draglines is proposed to be developed. Figure A-5 represents a section of the proposed mine. Stream M, a perennial stream inhabited primarily by minnows and darters bisects the mine property. A fisheries survey and evaluation of Stream M was recently performed by the state fish and game agency. Their findings were that few warmwater gamefish presently exist in this stream, because there is insufficient depths during low flow and vegetative cover is sparse along the bank resulting in relatively high water temperature during July and August. The evaluation of the coal reserves determined that the coal seam can only be economically mined to the limits depicted in Figure A-6. Due to the present condition of the stream, the regulatory agency has approved the permanent relocation of the section of Stream M as shown in Figure A-6 with the stipulations that (1) stream habitat for warmwater gamefish be improved, (2) considerations are made to develop riparian habitat, and (3) the relocated stream must be natural in appearance.

Problem Identification

The mining company is therefore faced with several problems. The stream is to be relocated in a wooded area that must retain its undisturbed characteristics, yet the new channel must be stable. In this case study, there are a multitude of considerations. For purposes of discussion in this text, the focus will be on three items: (1) streambank stabilization on a newly constructed meandering stream, (2) preservation of streamside vegetation, and (3) creation of instream habitat.

Streambank Stability

To meet the requirement that the stream have a natural appearance, meanders were included in the preliminary design. Incorporating meanders, however, complicated the design of the channel since standard engineering procedures are not sophisticated enough to account for changes in the direction of the stream channel. This situation was further complicated by potentially highly erosive channel bed and bank material. The first step accurately defined the materials or substrate in which the new channel was to be excavated. Under the direction of a geologist or geotechnical engineer, a test boring and soil sampling program was conducted along the proposed relocation route. Based on this information, the next step was to apply methods such as the permissible velocities or tractive forces to determine channel design (see Chapter 4). In laying out the meander pattern, the first approach was to examine the existing stream course, but consideration was also given to the fact that the stream would probably re-establish its own flow path which, in all probability, would not entirely coincide with any constructed alignment. Thus, meanders were limited to gradual bends, even though the existing stream course consisted of more pronounced curves. Once the alignment had been set and expected maximum velocities determined, the areas along the reconstructed stream channel most subjected to erosion were identified.

Riprap was selected to protect the areas of potential erosion such as the outsides of bends and at the junctions of the new channel and the existing stream. The riprap was sized to resist scouring and then it was properly installed (Section 4.1.8). Finally, the streambanks were revegetated with species tolerant of site conditions (water, soil texture, slope). The seeding mixture and rate and the mulch rates were based on recommendations of the local Soil Conservation Service.

Preservation of Streamside Vegetation

The diversion was routed through woodland, preserving trees and shrubs along the channel to enhance the appearance and biological productivity of the stream. Construction activities and equipment movements were restricted to the excavated streambed. In certain areas, vegetation on one side of the channel had to be removed so that a dozer could gain access to the diversion. In areas where stream bank vegetation had to be removed, an attempt was made to preserve vegetation on the south side of the channel and to clear vegetation on alternate sides of the diversion to maintain a natural stream appearance.

Creation of Instream Habitat

Based on the state fish and game agency's report, the main factors limiting gamefish survival in the natural stream were inadequate flow depths and instream cover for fish reproduction and refuge. These two characteristics were compensated for in the new channel through the use of log and tip deflectors. The stream was suited for these devices because it is a low gradient stream and the logs would not be subjected to high velocities. During dry periods in the summer and fall, the deflectors concentrate flows, creating scour holes which provide refuge. The tip deflectors (Section 5.1.1) also provide overhanging cover for fish (Figure A-7). Placement and arrangement (See Figures 5-7 to 5-9) of the deflectors took into consideration the restrictions on the width of the stream. Another advantage created by the deflectors was to create instream meanders to help compensate for the conservative channel design that did not exactly mimic the existing stream pattern.

Fish and Wildlife Benefits

The project provided several benefits to fish and wildlife resources:

- Creation of a stable streambank will keep the stream within a narrow channel, thereby increasing flow depths, which is essential to fish survival during low flow periods in late summer and fall.
- By establishing streambank vegetation, sediment loading into the stream will be reduced, which improves water quality and protects aquatic organisms from the adverse effects of siltation of the streambed.
- Preservation of streamside vegetation creates riparian habitat and produces shade to moderate water temperatures.
- Providing current deflectors concentrates low flows and increases the available shelter and cover for fish.

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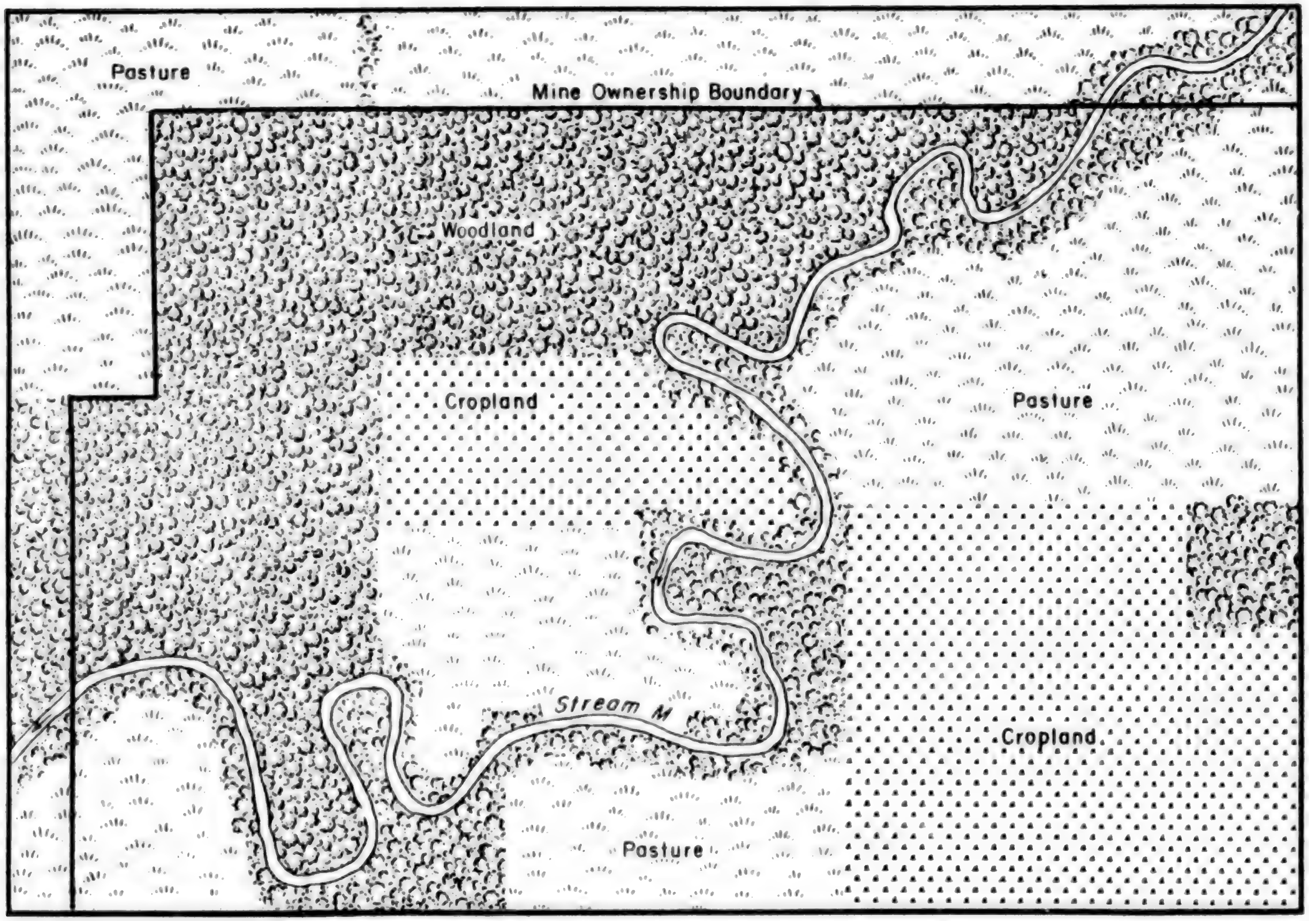

Figure A-5. Premining conditions.

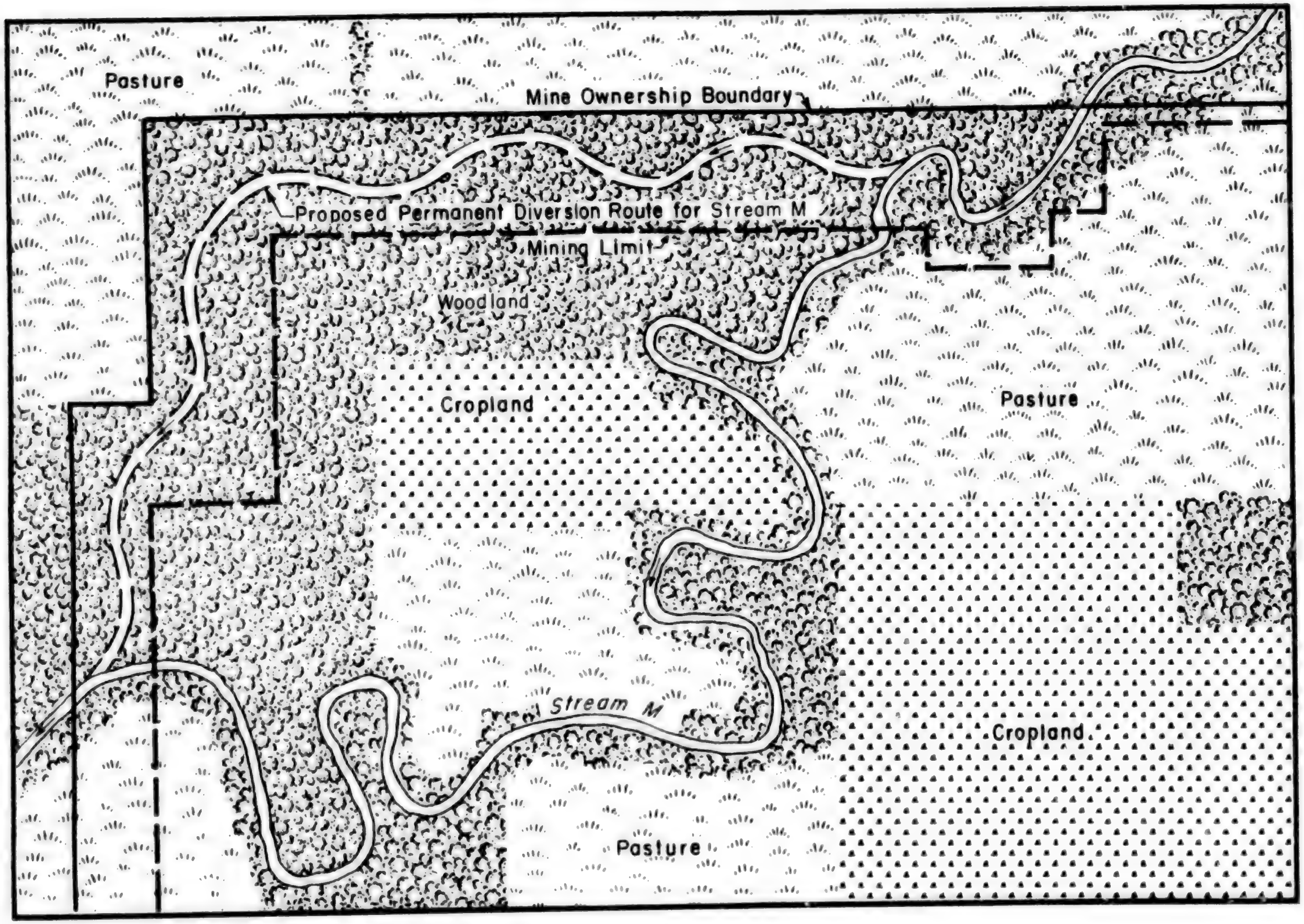

Figure A-6. Mine plan and proposed diversion route.

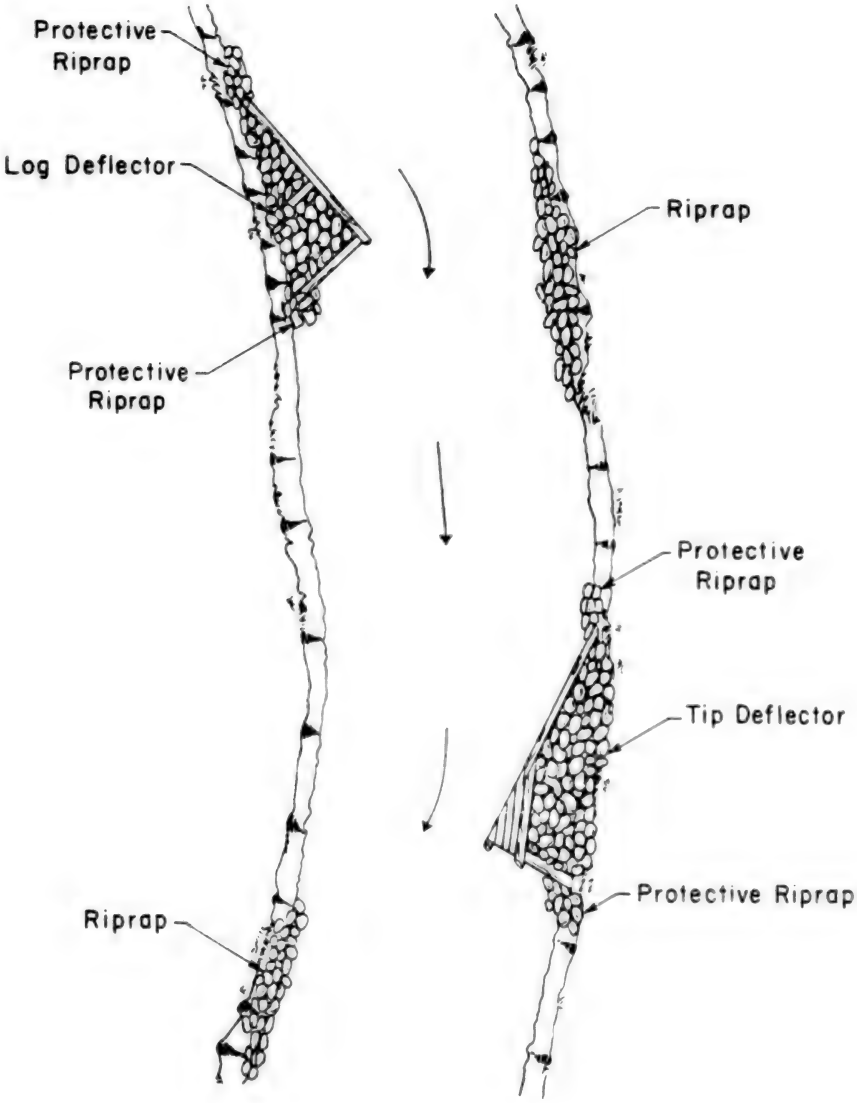

Figure A-7. Typical deflector arrangement proposed for stream M.

CASE STUDY NO. 3 - MOUNTAIN COAL PROVINCE

Setting

For purposes of this example, the mine is located in an area of gently rolling terrain near the foothills of the Rocky Mountains. Streams originating in the mountains above the study area are clear, cold and are characterized by high velocity flows suitable for native cutthroat trout. Near the mine, these streams become more turbid, slower moving, and are subject to greater temperature fluctuations as they proceed through the foothills. In this hypothetical study, one such perennial stream, Stream A, flows through a coal leasehold on which a truck-and-shovel area mine is proposed (see Figure A-8). Premining baseline studies determined that Stream A is a marginal coldwater fishery stream that supports a small rainbow trout population. Peak annual flows and highest velocities generally occur during snowmelt in late spring. The mining company has proposed to mine through the stream, creating a temporary diversion around the mining operation and then re-establishing Stream A along its original course in reconstructed spoil material after mining is completed.

Problem Identification

A premining analysis of the truck/shovel operation determined that a deficit of spoil material will occur as a result of coal removal. This deficit in spoil material would result in low-lying areas creating the potential for ponding water, and eventual salt accumulation. Secondly, the regulatory agency required that Stream A be capable of passing the 100-year, 24-hour flood discharge after reconstruction. However, preliminary design calculations indicated that to handle the design discharge, the channel would have to be so wide that under normal expected flows, water depths would be insufficient to maintain the rainbow trout population. The state regulatory agency has specified as part of the mining permit that sufficient instream cover and water depth be provided to support the rainbow trout population and to increase and improve the habitat in the reconstructed channel. Thus, the operator had to address the following permit stipulations.

1. How will the operator account for a material deficit without creating a depression that would eventually become a salt trap?

2. How will the operator design a channel that will convey the design discharge, yet maintain flow depths that are adequate for fish survival and reproduction?

3. How will the operator incorporate habitat structures and streambank protection methods that will withstand high velocities that occur during snowmelt?

Material Balance Deficit

As a solution to the material balance deficit, the final pit was not reclaimed. Stream A, which had been temporarily diverted around the mine site, was re-established along its approximate original course through the final pit. Considerations that had to be resolved before this project was initiated, included an estimate of what effects the project would have on water quality, fish movement and flow (see Section 4.1.6). Creation of the lake environment would benefit wildlife by providing them with a source of water and by providing areas for waterfowl.

Channel Design for Design Event

A narrow main channel was maintained by constructing a separate flood flow channel to handle discharges exceeding the capacity of the main channel (Section 4.1.10) (Figure A-9). The construction of the flood flow channel required additional planning and materials handling during the reclamation phase, but allowed the utilization of a smaller channel to handle the more typical flows experienced in Stream A. The narrow main channel provided sufficient flow to support the trout population.

Instream Habitat

Split rock check dams were constructed concurrently with the placement of random boulders to provide rainbow trout habitat (see Figure A-10). The advantages of using the split rock check dams (see Section 5.1.3) are that they will not impede fish from travelling throughout the stream reach, and when overtopped during spring runoff events, will help to create diversity in the streambed by forming pools. These scour holes will provide areas of refuge during low flows as well as providing shelter from high current velocities during floods. Random boulders (Section 5.1.4) are effective, inexpensive and stable if sized to withstand flood flows and provide shelter and cover.

Fish and Wildlife Benefits

By implementing the aforementioned suggestions, fish and wildlife resources were enhanced by:

- Creating a lake for a wildlife water supply and a new habitat type for aquatic organisms in Stream A.
- Providing a narrower channel and therefore increasing stream depths to promote fish survival in the summer.
- Creating stream diversity by scour pools below each check dam.
- Maintaining fish passage through the new channel through the use of split rock check dams.
- Adding habitat diversity through placement of random boulders and the development of scour pools.

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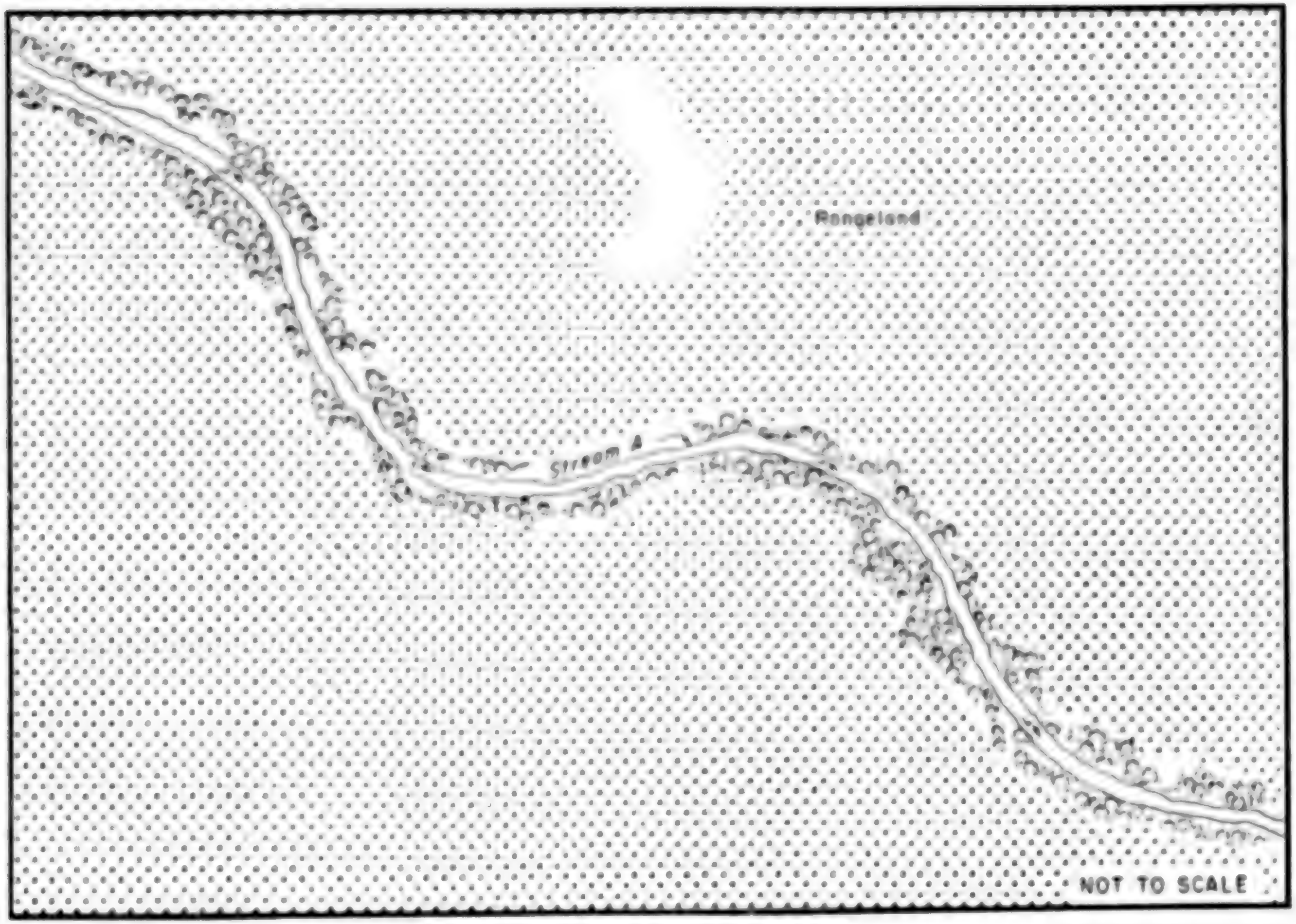

Figure A-8. Premining conditions.

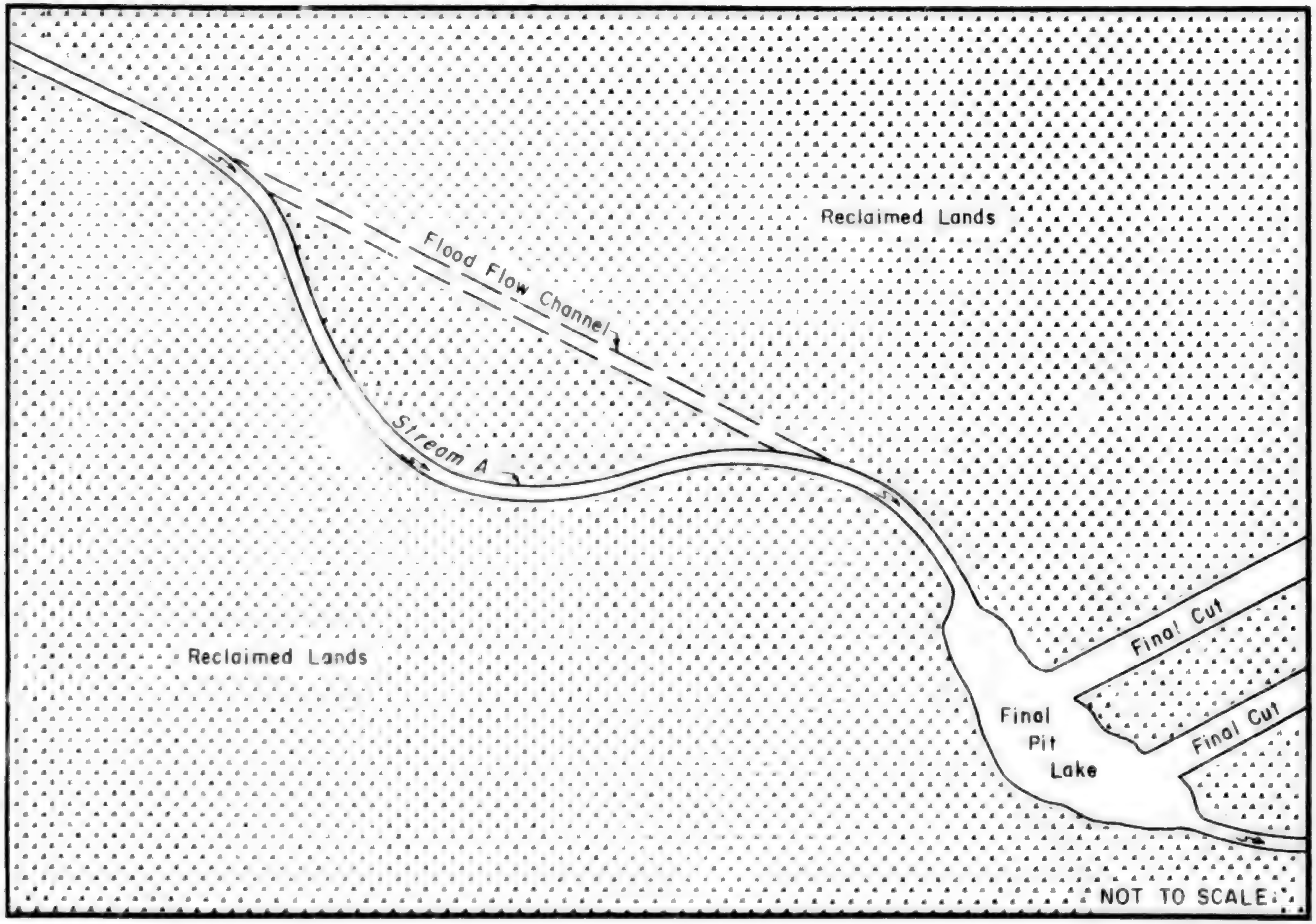

Figure A-9. Reconstructed creek with channel modifications.

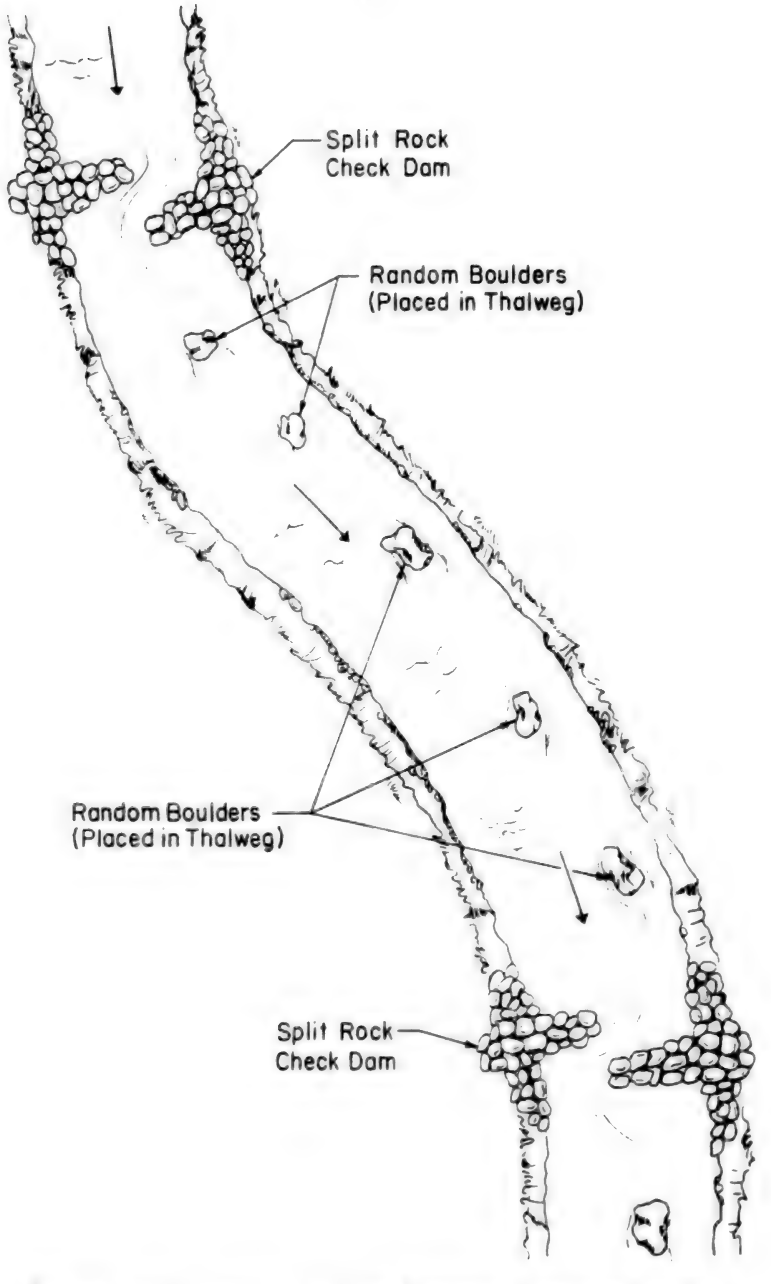
Split Rock Check Dam
Random Boulders (Placed in Thalweg)
Random Boulders (Placed in Thalweg)
Split Rock Check Dam

Figure A-10. Section of creek showing instream habitat devices.

APPENDIX B

FEDERAL AND STATE AGENCY CONTACTS

U.S. Fish and Wildlife Service

Headquarters

U.S. Department of the Interior
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Portland, OR 97232

Region 2
Assistant Regional Director --
Environment
U.S. Fish and Wildlife Service
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Albuquerque, NM 87103

Region 3
Assistant Regional Director --
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U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, MN 55411

Region 4
Assistant Regional Director --
Environment
U.S. Fish and Wildlife Service
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75 Spring Street, S.W., Suite 1276
Atlanta, GA 30303

Region 5
Asst. Regional Director --
Environment
U.S. Fish and Wildlife Service
One Gateway Center, Suite 700
Newton Corner, MA 02158

Region 6
Assistant Regional Director --
Environment
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, CO 80225

Region 7
Assistant Regional Director --
Environment
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AL 99503

Office of Surface Mining Reclamation and Enforcement

U.S. Department of the Interior
Office of Surface Mining Reclamation
and Enforcement
1951 Constitution Avenue, N.W.
Washington, D.C. 20240

Office of Surface Mining Reclamation
and Enforcement
Eastern Technical Center
10 Parkway Center
Pittsburgh, PA 15220

Office of Surface Mining Reclamation
and Enforcement
Western Technical Center
Brooks Tower - 1020 15th Street
Denver, CO 80202

U.S. Geological Survey
(NAWDEX and WATSTORE)

National Water Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
(703) 860-6031

National Water Data Storage and
Retrieval System (WATSTORE)
Chief Hydrologist
437 National Center
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Office of Water Regulations and Standards
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STATE AGENCIES

ALABAMA

Department of Conservation and Natural Resources
Division of Game and Fish
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Alabama Surface Mining Commission
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ALASKA

Department of Environmental Conservation
Division of Water Programs
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Juneau, AK 99811

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Division of Water Resources
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Department of Natural Resources
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Department of Natural Resources
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Department of Natural Resources
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The document should provide coal mining operators, surface mining management agencies, and other persons involved with potential and planned alterations to small streams located on and adjacent to surface mine sites with current information on practices to minimize harmful impacts to fish and wildlife resources. Stream alterations adverse to biological communities are identified and measures employed to counteract negative aspects of stream alterations are described. The complexities of integrating biological concerns into the often harsh physical and chemical conditions involved with stream alterations are considered and proven beneficial practices to fish and wildlife habitat are reviewed and described in detail.

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March 3, 1849

U.S.
FISH & WILDLIFE
SERVICE

END

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